THE

JOURNAL OF GEOLOGY

JULY–AUGUST, 1897

MORAINES OF RECESSION AND THEIR SIGNIFICANCE IN GLACIAL THEORY.[1]

CONTENTS.

INTRODUCTION.

The principal facts which form the basis of this paper were presented in an article read before the joint session of the Geological Society of America and Section E of the American Association for the Advancement of Science at Buffalo in August 1896.[2] They may be briefly summarized as follows:

During parts of the seasons of 1893, 1895 and 1896 the writer explored the eastern coast of Michigan southward from Mack-

[1] An abstract of this paper was read before the Geological Society of America at Washington, December 31, 1896.

[2] "Glacial Succession in Eastern Michigan." Abstract in Am. Geol. for October 1896, p. 234.

inac straits chiefly with the object of tracing the old shore lines. Incidentally, however, much information was gathered concerning the terminal moraines which lie in the same area. Their development and relations were found to be for the most part very simple. Between Mackinac straits and Toledo, Ohio, five moraines were found arranged in consecutive order or in series, and the series is regarded as complete within this interval. The work of the past season brought the moraines of Michigan into connection with those of Ohio and Indiana where their relations had been worked out by earlier observers — by G. K. Gilbert and N. H. Winchell in northwestern Ohio, by C. R. Dryer in northeastern Indiana, and by F. Leverett in western and southwestern Ohio.[1]

According to Mr. Leverett and Professor Chamberlin the drift of the Wisconsin glacial epoch extends down into southwestern Ohio nearly to Cincinnati.[2] Near this place its farthest limit is marked by a terminal moraine, and from this there is a series of moraines extending northward to the Maumee valley. Numbering the moraines up from the south the one that passes through Defiance is the tenth. By the work of the several observers mentioned, the whole interval from Cincinnati to the Straits of Mackinac has been explored, and the sum of the terminal moraines in the whole series is fifteen. And further, not

[1] GILBERT in the reports of the Geological Survey of Ohio, Vol. I, 1871, chap. xxi, p. 357. WINCHELL in Proc. A. A. A. S., Vol. XXI, 1872, pp. 171–179; Geological Survey of Ohio, Vol. II, 1874, pp. 56, 431–433. DRYER in the 16th, 17th and 18th reports of the State Geologist of Indiana, 1888 to 1894. LEVERETT in Am. Jour. Sci., Vol. XLIII, 1892, pp. 281–297; JOUR. GEOL., Vol. I, No. 2, 1893, pp. 129–146.

[2] MR. LEVERETT speaks of this as "the later drift." (JOUR. GEOL., Vol. I, No. 2, p. 138.) PROFESSOR CHAMBERLIN afterwards applied the name "East-Wisconsin formation" to this drift, and the same is now known as the "Wisconsin formation." (GEIKIE'S "Great Ice Age," 1894, p. 763 and map opposite p. 727. Also in JOUR. GEOL., Vol. III, No. 3, pp. 270 and 275.) PROFESSOR CHAMBERLIN recognizes, with a reservation of doubt, a division of the moraines of the Wisconsin formation into "earlier" and "later" groups. ("Great Ice Age," pp. 763–764.) But this division would make very little difference in the conclusions reached here. For in the Miami valley the first moraine north of Cincinnati is the only one belonging to the earlier group. All the rest of the series northward to Mackinac belong to the later group and are therefore a consecutive series in time.

Map showing Moraines of Recession between Cincinnati and Mackinac.

only is it ascertained that there are fifteen moraines between Cincinnati and Mackinac, but the conditions of glacial motion and drift deposition were so simple along the entire line that it is substantially certain that the series is full and complete. Three more moraines in the same series, but possibly not consecutive, were found north of the straits. In making the count the central axes of a connected series of wide open valleys was followed—up the Miami valley, down the Maumee, up the Detroit and St. Clair and thence northward along the west shore of Lake Huron. This course was chosen because the ice motion was naturally the freest in the open valleys where the resistance was least, and the oscillations of the ice-front were recorded there more distinctly than anywhere else. This line avoids all interlobate and other morainic complexes and follows the valley axes where the amplitude of the peripheral oscillations of the ice-sheet was naturally greatest.

On examining the configuration of the individual moraines and on comparing the intervals of distance between them (shown on the accompanying map) it is apparent that the principal irregularities of the moraine series are due to topographic influences. As the ice-sheet crept along it moved forward farthest and fastest in low wide valleys like the St. Clair-Detroit valley, and it lagged behind on the hills and highlands as on Blue Mountain south of Georgian Bay, on the highlands south of the Straits of Mackinac, and on the "thumb" between Saginaw Bay and the south arm of Lake Huron. The relative width of the valley and the relative height of the bounding highlands had a considerable effect upon the amplitude of the oscillations at any given point. For in a narrow valley, between relatively high side lands, as was probably the case to a slight extent in the Miami and Sciota valleys, the ice movement was cramped and the amplitude of oscillation more or less reduced. The ice-lobes that spread away southward from the Huron, Saginaw and Erie lake basins were wonderfully sensitive to topography. Differences of level of the general land surface over which they moved amounting to as little as a hundred or even fifty feet determined

the direction of flow and shaped the lobes. The intervals between the moraines show some irregularity, but on a close study of the relief of the region, with due allowance for its influence upon the ice-motion, it seems clear that if the uneven features of the land surface had been wholly absent the moraine series would have been perfectly regular, either with equal intervals or intervals showing a regular order of variation.

VALUE OF THE CINCINNATI-MACKINAC MORAINE SERIES AS A BASIS OF INTERPRETATION.

So far as known to the writer there is no other glaciated area of like extent where a moraine series is found so simple and complete as that between Cincinnati and Mackinac. Similar moraine series are known in many other places—most notably in the adjacent areas of the Sciota Valley in Ohio, in southwestern Michigan and northwestern Indiana, and in Illinois, Iowa, Minnesota and the Dakotas, but in none of these regions are the phenomena of equal simplicity or completeness. A few moraines in series are known in the eastern states and New England, and a few also in Europe, but in all these regions they fall far short in comparison. The series of moraines extending northeastward from Defiance to Rochester, N. Y., may ultimately prove to be as good as that extending to Mackinac, but at the present time it appears to be incomplete. Eastward from Cleveland especially the lower moraines are closely packed on the steep northward slope. In the Dakota-Minnesota series Mr. Upham finds twelve moraines,[1] but it is perhaps somewhat doubtful, as was recently pointed out by Professor Todd, whether all these moraines are in one series.[2] In Illinois, western Indiana and southwestern Michigan, Mr. Leverett finds a number of moraines in series, but there are overlaps in the area, and in Illinois, especially, the individuals join and separate so often, form-

[1] "The Glacial Lake Agassiz," by WARREN UPHAM; Monograph XXV, U. S. Geological Survey, 1896, pp. 139–141. Also, Twenty-second Ann. Rept. Minn. Geol. Survey, Part III, 1894, p. 45.

[2] "A Revision of the Moraines of Minnesota," by J. E. TODD. Abstract in Am. Geol. for October, 1896, p. 225.

ing a series of complex loops, that the system appears at present confused and a complete and simple series is not easily made out. The moraines of the Saginaw lobe in all probability make a simple series of at least eight or ten members, but they have not yet been fully explored. The chief element of confusion in these several areas appears to be due mainly to the influence of a relatively complex topography. There may have been other causes of complexity, but the land relief is clearly the most important.

The individual moraines of the Cincinnati-Mackinac series are also as a rule simpler in their reliefs, in the curves by which they cross the valleys, and the intervals between them are wider and more regular. Their relations to each other and to the adjacent higher lands are also simpler.

On account of their completeness and simplicity, therefore, the moraines of the Cincinnati-Mackinac series constitute the best body of facts now known for the study of the cause of the oscillations of the retreating ice-sheet, and there appears to be little prospect of ever finding a better one. With few exceptions a comparison of other moraine series shows at once that the reason the Cincinnati-Mackinac series is so simple is that the land relief which the ice encountered along this line was of the simplest sort. Such a comparison in nearly every instance strengthens the conclusion that if the ice-sheet had moved over a perfectly plane surface the moraines would have been laid down at regular intervals or else at intervals varying progressively in a regular way. In short, the departure from perfect simplicity and regularity in the moraine series of any ice-lobe seems to be in a general way proportional to the magnitude, number, and complexity of arrangement of the larger topographic features which it encounters.

KNOWN PERIODIC OSCILLATIONS OF CLIMATE.

It has been supposed by many, and apparently with good reason, that northern lands were elevated to relatively high altitudes during the Ice age. This is held by some to have been

the chief causal condition. But whatever the cause of the Ice age itself may have been, it seems hardly possible to account for the moraines of recession by any scheme of ups and downs of the solid earth. The moraines themselves indicate that the oscillations of the ice-front were of a periodic nature, and therefore dependent upon the operation of a periodic cause. All geological forces that are purely terrestrial are necessarily derived from the interior of the earth, and there is no evidence that their activities are periodic, although they may recur at irregular intervals. Still less is it possible to conceive of true periodicity in the surface manifestations of purely terrestrial forces, such, for instance, as would be required to explain periodic movements of elevation and subsidence over wide areas, especially where the amount of the successive movements would have to be regulated to the extreme nicety of progressive variation requisite to produce the climatic cause of the moraines of recession. All such supposable terrestrial causes may therefore be safely put aside.

To find a source for periodic causes we are compelled to turn to astronomy. According to established doctrines the only way in which astronomical forces can be supposed to influence glaciation is through climate. The annual period of climatic change is so short that it is, of course, out of the question. A period of climatic change in rounds of about thirty-five years has been deduced by Forel and others from the study of the variations of glaciers and of rainfall.[1] But, as will be shown farther on, this too seems far too short. After this the only known period of climatic variation is that due to the precession of the equinoxes,

[1] F.-A. Forel. (Archives. Sci. Phys. Nat., May 15, 1886, p. 503.) Forel points out that the variations of rainfall and air temperature, as deduced by C. Lang, agree with his own periods of variation in Alpine glaciers. (Also Am. Jour. Sci., for July 1886, p. 77.) In Forel's latest writing on this subject ("Les Variations Periodiques des Glaciers," Genève, 1895) he finds the grounds for deducing a definite period to be rather unsatisfactory. He finds that glaciers of different sizes and lengths do not show the effects of causes of advance or retreat synchronously. After a few seasons of increased precipitation all glaciers tend to advance, but small ones advance sooner than great ones so that they do not attain their maxima at the same time. A small glacier will reach its maximum and get far back on its retreat before a greater glacier attains its maximum advance — a result that is natural from the fact that the effects

and the movement of the perihelion of the earth's orbit. Mr. G. K. Gilbert has used this period of climatic oscillation in connection with another matter. His statement relating to the length and variability of the precessional period is concise and convenient. "The precessional period is about 26,000 years, but the position of the perihelion also moves—for the most part in a direction opposite to that of the equinoxes—and the resultant of the two motions has an average period of about 21,000 years. It is not absolutely regular, but ranges ordinarily within 10 per cent. of its mean value, and exceptionally to 50 per cent. above and below."[1] The period at 21,000 years seems too long, but if we take it at its minimum of 10,500 years, it may not be.[2]

THE THEORETICAL EFFECT OF PRECESSIONAL OSCILLATIONS OF CLIMATE UPON THE ICE-SHEET.

Let us see in what manner the astronomical forces would work, supposing the oscillation of the ice-front to be due to precession. Precession is produced by the rotation of the axis or pole of the earth around the pole of the ecliptic. The figure thus described on the celestial sphere is not in reality a true circle, but for the purposes of this paper it may be assumed that it is, without in any way impairing the general truth or validity of the conclusions reached. The general idea of the influence of precession upon terrestrial climate has been so often discussed that it is hardly necessary to dwell at length upon it here. But it is

of causes of advance or retreat proceed in waves downward from the névé to the end of the ice-tongue. From this and other causes of complication he finds it hard to make out clearly any regular period of variation. Nevertheless, it is probable that a thirty-five-year period exists. The progress of investigation along this line is well summarized by Professor H. F. Reid, "Variations of Glaciers," JOUR. GEOL., Vol. III, No. 3, 1895, p. 278 et seq.

[1] "Sedimentary Measurement of Cretaceous Time," by G. K. GILBERT. JOUR. GEOL., Vol. III, No. 2, 1895, pp. 121–127.

[2] There is a possibility that the period of precession during the glacial epoch was considerably shorter than the minimum of the modern calculation. Perhaps the chance of this seems very remote, but there are small changes going on, now apparently secular, which in so great a lapse of time may prove to be periodic and may come to be of prime importance in their effects on terrestrial climate.

necessary to see clearly how the position or place of the ice-front is related to this kind of climatic change. The change of climate from this cause does not go on with the rotation of the earth's pole *pari passu*. For the pole, under the simplified conditions here postulated, moves in a circle and changes its position at a uniform rate. The effect of this movement on climate is to produce a periodic or oscillatory change to and fro between two extremes or climaxes, and these changes go on in an endless alternating series, from cold to warm, from warm to cold, from cold to warm, and so on. In glacial times a climatic variation of this sort, even if it were slight in amount, must have had its effect on the ice-sheet. As climate grew more severe the ice-sheet would advance its front all along and spread over a larger area, and as climate moderated the ice-front would draw back and the area of the ice-sheet would be reduced. Thus it may be demonstrated that the effect of a precessional oscillation of climate upon the ice-sheet would be to cause it to alternately increase and decrease its area by a series of expansions and contractions, and this process would necessarily be accompanied by a corresponding series of alternate advances and retreats of the ice-front. We are thus enabled to infer the character or manner of the oscillations of the ice-front, supposing them to be due to precession. They would obviously follow the manner of what is called simple harmonic motion. If a wheel be made to rotate on a fixed vertical axis a point or peg on its rim describes a circle when viewed from above. But if we look at the wheel edgewise, or from the side, the peg appears to move to and fro along a straight line, more slowly near the ends, fastest in the middle, and coming to rest for an instant at each extremity. The manner of the apparent motion is like the swinging of a pendulum viewed from below. This is the manner in which the forward and backward movements of the ice-front would take place if produced by precession. As the cold increased after a warm climax, the ice-front would advance, at first slowly, but at increasing rate, until the middle point of the oscillation was reached; then more and more slowly until it came to rest at its cold or

forward climax, where it would halt and build a terminal moraine. Then as climate ameliorated the ice-front would retreat in the same fashion and at its warm or backward climax it would again halt and build a moraine. The moraines of the cold climaxes would always be built after an advance movement, and would therefore be left standing. But the moraines of the warm climaxes would always be built after retreats and just before advances, and would therefore be overridden and destroyed. From these considerations it is plain that the time during which the ice-front would stand at or near its extreme forward position while building its terminal moraine at the cold climax would be only a fraction of the whole precessional period. The precise value of this fraction depends upon three factors: (1) on the period or duration of the precessional oscillation of climate; (2) on the amplitude of the oscillation of the ice-front, and (3) on the width of the drift belt which takes the form of a terminal moraine at the cold climax. The character of the moraine built would vary considerably according to the manner of combination of long or short periods with small or great amplitudes. Other factors, such as the quality and quantity of the drift, the land relief, the situation with reference to the margin of the lobe (frontal or interlobate), latitude and local climatic influences modify the character of the moraines more or less, but need not be discussed further here.

By way of illustration let us consider a hypothetical case Suppose the amplitude of oscillation to be thirty miles, which is probably not far wrong for certain localities, and the period to be 10,000 years, which is in round numbers the supposed minimum value of the precessional period. The moraines are from two to ten miles wide, the average being not far from five. Their width varies considerably in different regions and different situations, but the figures given are approximately true for northwestern Ohio, northeastern Indiana, and southeastern Michigan

Figure 1 represents a simple harmonic motion in which *A B C D* is the circle of reference and represents the circle which the pole of the earth describes on the celestial sphere in 10,000

years. The diameter *A C* may be taken to represent the amplitude of the oscillation of the ice-front as affected by the precessional oscillation of climate, and is put at thirty miles. Of course the ice keeps melting as it moves forward so that there is no material thing that constantly accompanies the ice-front as it changes its position. But we may imagine a point which shall keep its place constantly at the front edge. This point would move to

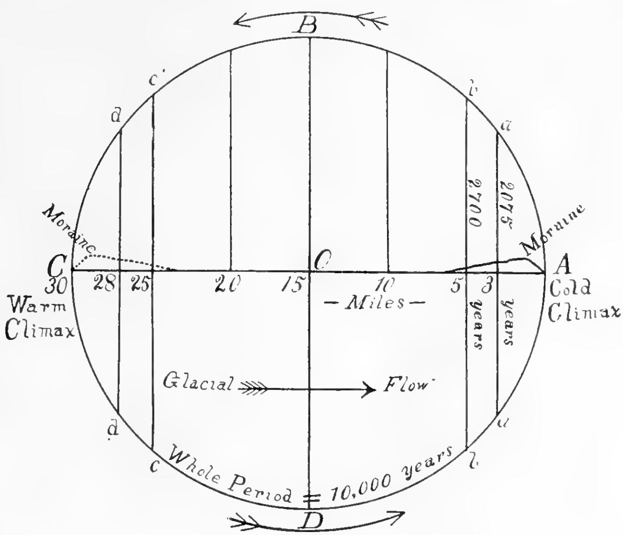

FIG. 1.

and fro with the ice-front on the line *A C*, following the order of the precessional changes of climate. An arrow within the circle shows the direction of the general glacial flow, which is maintained in the glacier itself through all phases of advance and retreat of the ice-front. The climaxes of cold will therefore be at *A* and the climaxes of warmth at *C*, and the ice-front will have a period of rest at each of these points. When the ice-front passes *O* it will always be moving at the maximum rate, whether of advance or retreat. As the ice-front moved forward from *O* to *A* its rate of advance would decrease, and would become very slow on approaching near to *A*, and the retreat

from *A* to *O* would have the same character in reverse order. The five miles nearest to *A* represents the approximate width of the belt in which terminal moraines at the cold climaxes are built. If the whole period of precession be 10,000 years and the amplitude thirty miles, it is easy to show that the ice-front would be within the five-mile belt (*bb'*) about 2700 years, and within the three-mile belt (*aa'*) about 2075 years. A period of terminal moraine building of the same duration would also take place at *C*, the warm end of the oscillation, but the moraines built there would always be overrun and destroyed at the next advance.

If this process were carried on with ideal simplicity the resulting forms of the terminal moraines at the two extremes of oscillation would be substantially as represented in cross section in the figure. Those at *A* would have relatively short, steep front slopes and long, gentle back slopes, while those at *C* would have long, gentle front slopes and short, steep back slopes. In the moraine series as we have it, all those made at *C* have been destroyed, and we have left only those made at *A*. We shall see presently that where the conditions were simplest the moraines do in fact show plainly a tendency to take the form shown at *A*.

If the period of precession were 20,000 years, the amplitude remaining the same, the time of the ice-front in the five-mile belt would be doubled, or 5400 years. On the other hand, if the period were 5000 years the time in the five-mile moraine belt would be 1350 years, and in the three-mile belt 1037 years.

The character of the moraine would also be affected by the amplitude of the oscillation, the period remaining the same. The amplitude would necessarily vary greatly in different places, the chief determining condition being the character of the land relief and the relation of the ice to it. Against a steep slope towards the ice the oscillation would be greatly reduced and the moraines would be closely packed together, as is seen in interlobate areas. In wide flat areas, like the Saint Clair-Detroit and Maumee valleys, the amplitude would be at its greatest.

The general application of this idea to the oscillations that took place is plain on a comparison of the course of any two contiguous moraines of the series from their apexes in the center of the valley to their turning point in the interlobate. The Fort Wayne and Defiance moraines are nearly fifty miles apart at their apexes, but they converge as they rise toward the northeast until they are only eight or ten miles apart a few miles beyond Adrian. On this basis it would be expected, further, that the moraines themselves would be comparatively wide and flat where the amplitude of oscillation was great and *vice versa* Here again there is some evidence of agreement of fact with theory. With the period of oscillation at 10,000 years and the amplitude at 100 miles, which appears to have been its approximate measure after passing Fort Wayne, the five-mile moraine belt would be occupied by the ice-front about 1345 years, and a ten-mile belt about 1920 years.

THE CHARACTER OF THE GLACIAL OSCILLATIONS AS REVEALED BY THE DRIFT.

Assuming that the moraine series was produced by a climate oscillation it becomes a matter of the highest importance to discover if possible what the character of that oscillation was Did the ice-front merely retreat and halt in the simplest possible rhythmic fashion, or did it follow a more complicated movement of alternate retreats and readvances with halts between? It would be expected that the way in which it was built would make some difference in the form or shape of a moraine. If the moraines took any dominant or common form, and if that shape corresponded to one that would result theoretically from some particular process, it would be fair to presume that that had been the method of their building.

At a first glance it would appear that the moraines show no recurrent features that are particularly suggestive in this respect, and it must be admitted that many of them, perhaps the majority, do not. At least they do not show such features clearly enough to be readily recognized. But there are some of the

moraines that do show a marked tendency to take a particular form, and it is upon these that we must rely.

Here again it is necessary to recur to the law of the higher value of the simplest phenomena as a basis of interpretation when compared with those that are more complex. If in the present state of our knowledge we go to the compounded moraines of interlobate areas, or to the more or less obscure moraines of the mountains or hilly eastern states, it will be found very difficult to reach any satisfactory conclusion. But some of the moraines of northern Indiana, northwestern Ohio, and southeastern Michigan present the utmost simplicity of form, and were built under the operation of forces acting in the freest and simplest way possible. Upon these moraines, and especially upon those of them that seem to be most typical in their simplicity, I rely mainly for the conclusions reached.

The moraines of northeastern Indiana have been studied in detail by Professor C. R. Dryer, from whose report I quote as follows:

> The peculiar topography of the Wabash-Erie region in Indiana would be strikingly shown by a section along any line radiating southwesterly or northwesterly from Paulding, Ohio. Such a line would run nearly level across the Maumee Lake bottom to the Van Wert and Hicksville Ridge, then rise 80 to 100 feet in four or five miles to the crest of the St. Marys and St. Joseph moraine, then fall fifty feet in about one mile, then cross a level interval of from one to ten miles, then show a second gradual rise and more abrupt fall, across the Wabash-Aboite moraine, and the second terrace averaging about sixty feet higher than the first. In the southern portion two more terraces lie beyond the Wabash Ridge.[1]

[1] Sixteenth Ann. Report of Indiana State Geologist, 1888, p. 123.

My attention was first called to the remarkable series of terminal moraines in northeastern Indiana and northwestern Ohio by the work of Professor Charles R. Dryer in the summer of 1886. As assistant to the state geologist, Professor Dryer was at that time making a survey of the northeastern counties of Indiana. Some acquaintance with the features of eastern Indiana southward as far as southern Randolph county and also with the region around Saginaw Bay in Michigan led me to extend the series provisionally, recognizing its probable incompleteness, to those regions. The idea that these moraines might mark precessional variations of climate was adopted by me then as a tentative hypothesis. The drift of opinion since then among American geologists, however, has been largely against anything like so

This is distinctly the character that should be expected in moraines built at a climax of advance in which the advance, the halt and the subsequent retreat take place after the manner of the cold climax of an oscillation like that shown at *A* in Fig. 1 above. The crest of the ridge is toward the front edge, the back slope is long and gentle, while the front slope is shorter and

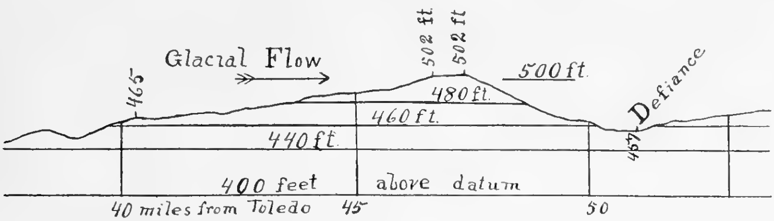

FIG. 2. Profile of Defiance Moraine.

steeper. This type of moraine is well illustrated in cross section by the profile of the Wabash Railway as it passes over the Defiance moraine east of that place. This is shown in Fig. 2.

As shown on this profile the crest of the moraine rises above

liberal an allowance of time for the glacial retreat as this hypothesis would seem to require. Moreover the moraine series remained fragmentary and incomplete until a year or so ago, so that there was not a sufficient foundation of fact to warrant the presentation of the idea. Nor had the remarkable Greenland explorations of Chamberlin, Salisbury, and others furnished the present strong foundation for the idea of slow motion of ice-sheets and slow transportation and deposition of drift. Without adopting the idea of precession as a cause, Professor Dryer fully recognized the general significance of the moraines, as the following words from his report show. After speaking of the possibility that each moraine marks the culmination of a separate glacial epoch, he says: "It seems more probable, however, that they are moraines of recession and mark halting places in the retreat of one and the same ice lobe. When their uniformity of mass, strict parallelism and occurrence at regular intervals are taken into account, the whole arrangement will perhaps prove to be unique among the glacial phenomena of North America. Their greatest importance lies in the evidence which they afford of regular periodical oscillations of climate. The outer edge of the ice lobe occupied a certain position long enough to form a moraine five miles wide and 100 feet high; it then fell back fifteen miles and occupied another line long enough to form a similar moraine. These alternating halts and retreats were repeated four or five times, the last retreat being thirty [fifty?] miles, and the last moraine, the Blanchard Ridge of Winchell, being smaller and less symmetrical" (p. 124).

its base somewhat more than forty feet, but the real crest is somewhat higher than the railroad track. The front or western slope is about two and a half miles long and the eastern or back slope about seven miles. It has been suggested that the moraines that show this form owe their steeper front slopes to the action of marginal glacial rivers which have carried off the deposit on that side. No doubt there was a slight influence of this kind in some cases, but there certainly was none in the case of the Defiance moraine, for it was laid down in about sixty feet of still water (glacial Lake Maumee) and there was no chance for a stream to act until the ice-front had retreated beyond Detroit nearly to Port Huron. While the Leipsic beach was being made the water still stood about thirty feet deep at Defiance, and it was only when it fell to the level of Lake Whittlesey (Belmore beach) that marginal rivers began to exist. The depression shown at Defiance in the profile is the bed of the Maumee River which began to flow at the same time. But the Maumee is a much larger stream than Tiffin or Bean Creek that comes in from the north along the moraine front, or the Auglaise River, which comes in from the south in the same relation. Formed under such circumstances it is obvious that the Defiance moraine was originally shaped in the building as we find it now, and does not owe its form to the action of a border river. Part of the Saginaw moraine, between Ubly and Cass City was probably steepened by the large rapid outlet river which flowed along its front, but apparently none of the other moraines of this type were notably affected in this way. The rest of the Saginaw moraine is a fine specimen of the type here referred to.[1]

This character of the moraines, however, is not confined to the particular tri-state area mentioned above. The same general type is only a little less distinctly developed in several other places, and is recognized by other observers. Mr. Leverett,

[1] Some account of Lake Whittlesey and the Saginaw and Port Huron moraines with brief mention also of the Toledo and Detroit moraines may be found in "Correlation of Erie-Huron Beaches with Outlets and Moraines in Southeastern Michigan," Bull. G. S. A., Vol. VIII, 1897, pp. 31–58. Also "Glacial Succession in Eastern Michigan," abstract in Am. Geol., Oct. 1896, p. 234.

speaking of the glacial drift of the northeastern third of Illinois, says:

> In the portion of the state covered by the newer drift there is a succession of morainic ridges formed by the ice-sheet during its retreat from the Shelbyville moraine. These ridges are separated by drift plains or basins from a mile or two up to thirty or forty miles in width. These plains usually show a gradual rise on their landward (west and south) borders, while on the iceward borders (toward the Lake Michigan basin) they are found to rise abruptly to a moraine. The streams which now drain this region naturally choose the axes of these basins for their main channels while the slopes carry the tributaries. It is the long slopes on the west and south, and the short slopes on the opposite side which have caused the tributaries of the streams to be mainly from the west and south.[1]

It will be noted that Mr. Leverett speaks of the slopes of the plains rather than of the moraines. Each moraine, however, may be regarded in some sense as the projecting upward edge of the gently inclined plain that merges with its back slope. Professor Todd notes this relation in his description of the moraines of Dakota where he says:

> It is assumed that the reader is familiar with the generally recognized features of drift formations, such as the undulating topography and the series of drift deposits, covering an area with successive layers of till in a manner which might be compared to a nest of spoons of assorted sizes, the smaller lying inside the larger. Of these spoon-shaped deposits, the moraines form the outer rims.[2]

It is very gratifying to be able to add to the weight of the foregoing opinions that of Professor Chamberlin, whose study of glacial problems has been close and prolonged, and whose experience in observation is probably wider than that of any other one man. It is hardly less than remarkable that his views of the glacial retreat should accord so closely with the requirements of the hypothesis here presented.

But so far as known to the writer this manner of glacial

[1] "The Water Resources of Illinois," by FRANK LEVERETT. Extract from 17th Ann. Rep. U. S. Geol. Surv., 1895–6, p. 13. Also in "Pleistocene Features and Deposits of the Chicago Area," Chicago Academy of Science, Bull. No. II, May 1897 p. 17.

[2] "The Moraines of the Missouri Coteau and their Attendant Deposits," by JAMES E. TODD, Bull. U. S. Geol. Sur. No. 144, 1896, p. 11.

retreat has not been associated by Professor Chamberlin with the causes here suggested. According to his view the drift of each main ice invasion was laid down in imbricate fashion; that is, there was a continual oscillation with moderate readvances as the general retreat progressed, so that the drift was laid down in successive overlapping sheets somewhat like the weatherboards on a frame house, or the shingle rows on a roof. In Geikie's *Great Ice Age*, under "The Imbrication of the Drift Series,' beginning on page 736, his views are given as follows:

> The drift deposits of the great plain region of North America may be looked upon as a series of sheets overlapping each other in imbricate fashion; the outermost disappearing beneath the next inner, and this, in turn, dipping beneath the succeeding, and so on. The outer uncovered zone of each sheet retains its original form, except as modified by superficial agencies, but the inner buried zone was much modified by the over-riding ice during the later advances. In a general view of the drift, it is important to grasp clearly this conception of the overlapping of the sheets, and to distinguish this imbricate structure from the simple stratigraphical superposition of marine sediments on the one hand, and of simple morainic corrugations following each other in concentric recessional lines on the other. It is, furthermore, important to observe that this is only a superficial conception of the drift series. Theoretically, there are at least two of these imbricate series for every period of glaciation, and the order of imbrication takes on opposite phases. During the first part of the glaciation, when the ice on the whole was extending, though by alternate advances and retreats, the later were generally greater than the earlier advances. During the succeeding stage, however, when the ice was, on the whole, retiring (though by oscillations) the later advances generally fell short of the earlier. In the case of the lower or older series of glacial accumulations, therefore, the later deposits generally reach farther south than the earlier ones, whereas, during the recessional stages of glaciation, the earlier sheets extend farther south than the later. These two imbricate series of sheets of contrasted order represent the two great halves of a period of glaciation. If there were two or more entirely distinct periods of glaciation theoretically the double imbricate series repeated itself accordingly. . . .

There is one other class of facts that may ultimately be added to the proof of readvances in the oscillations. Bowlder belts, at least in certain situations, are believed to indicate readvances. Respecting the source of the bowlders themselves it seems safe to say that ninety-nine out of every one hundred in

western Ohio, in Indiana, and Illinois are of Canadian origin, and nearly all are of the hardest crystalline varieties. Considering the dominant englacial mode of transportation, the continual and very complicated changes in the direction of glacial flow and the dispersion from the lobate axes, it becomes extremely difficult, if not altogether impossible, to account for the bowlder belts except by the intervention of some later agency of bowlder concentration—some agency that operated near where the bowlder belts are now found. It seems impossible that any marked bowlder belt could have been brought all the way from Canada with the bowlders in such close relationship as that in which they now lie. Some of the bowlder belts of southwestern Ohio, southeastern and western Indiana are very pronounced in their development. It is conceivable that they might have been formed by the marginal concentration of superglacial or englacial bowlder trains, but it is hard to think of those trains as coming directly all the way from Canada.[1] The distribution of bowlder belts is peculiar and indicates that the conditions of their production are exceptional. One moraine may show a well-formed bowlder belt, while its neighbors parallel with it in front and behind have none. The diverse composition of the bowlders seems also to be against the idea of concentrated bowlder trains. In short, it would seem that we must look much nearer than Canada for the cause of their very local concentration. The only local cause that seems available grows out of the relation of the readvancing ice-front to powerful lines of drainage at or near the edge of the ice. If, during the building of a terminal moraine, a powerful stream of water sweeps past the front of the ice so as to carry away the finer material the bowlders may be left on the surface in greater numbers than usual. Several of the well-known abandoned outlets have more or less of this appearance. But where this is the whole process the bowlders remain in a low position with respect to the surrounding lands. If, however, a readvance of the ice

[1] "Bowlder Belts Distinguished from Bowlder Trains—their Origin and Significance," by T. C. CHAMBERLIN. Bull. G. S. A., Vol. I, 1890, pp. 27–31.

takes place the bowlders in the channel may be gathered up and transported some distance and finally be deposited on or in a rugged hilly moraine even to its topmost parts. In being carried forward the bowlders may be more or less dispersed, or they may be concentrated, or neither of these effects may appear. In each case it depends mainly upon the relation of the river

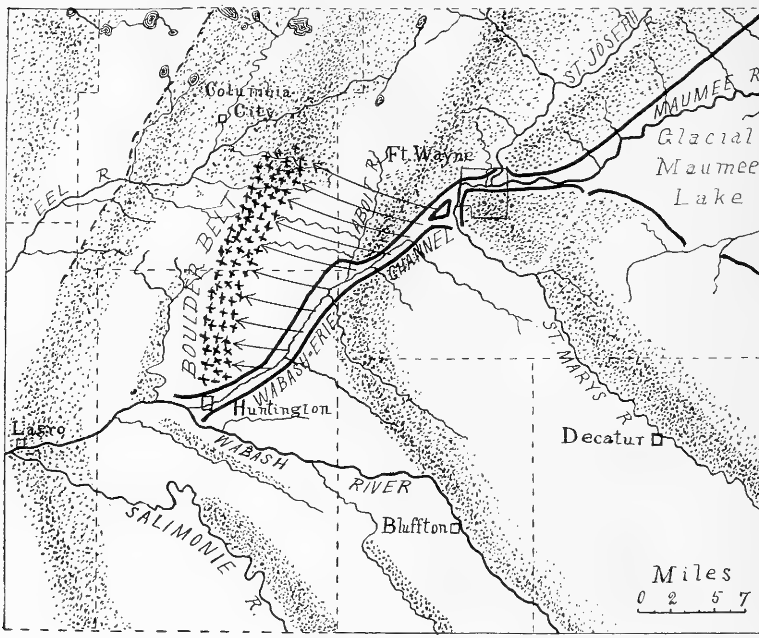

FIG. 3. Showing relation of the Whitley bowlder belt to the Wabash-Erie channel.

channel to the direction of ice-motion. If the channel were straight and also normal to the ice-front the readvancing ice would carry the bowlders all forward down the channel and concentrate them in a pile where it stopped. If the channel lay athwart a pointed ice-tongue and close in front of it, the readvance would disperse the bowlders somewhat. There is a bowlder belt in Whitley and Huntington counties, Indiana, which may be due to partial concentration by a readvance diagonally across the bed of a great river corresponding to the stream that

afterwards existed as the outlet of the glacial Maumee lake. The accompanying sketch map shows the relation. Dryer and Leverett show this belt on their maps.[1]

The disposition of this belt seems to show that the ice-front had retreated at least to Fort Wayne from the moraine next west of the bowlder belt in Whitley county, and halted while the large river excavated a channel about where the present old outlet bed is between Fort Wayne and Huntington. Then by a readvance the bowlders which had been left in this bed were carried forward by the ice, which moved in a direction normal to the ice-front, but diagonally across the river bed, and deposited them in the Whitley morainic bowlder belt. If this took place, then it is plain that the ice-front had retreated to Fort Wayne and that it readvanced over more than half the space it had just uncovered at the preceding retreat which was, therefore, not less than thirty miles.[2]

This interpretation of the Whitley belt is not yet a sure inference, for further and more particular investigation will be required to fully verify or disprove it. The Montgomery-Benton county belts seem to be somewhat similarly related to a readvance over a part of the Wabash River bed, and possibly to a former river bed about where Wild Cat Creek is now, and the Iroquois belt may have had a similar relation to the Tippecanoe River or to a glacial river that crossed from the Kankakee to the Wabash farther west, but was obliterated by the readvance.

[1] DRYER in 18th Report of Indiana State Geologist, 1894, p. 84. LEVERETT in the "Inland Educator" (Terre Haute, Ind.), for August 1896, opposite p. 24. DRYER shows only that part of the bowlder belt which lies in Whitley county; LEVERETT shows it extending on southward nearly to Huntington. The accompanying sketch is compiled from their maps.

[2] The range or amplitude of oscillation may have been considerably more than thirty miles. Indeed, after the ice-front left Fort Wayne it must have been greater, for the four intervals from this place to Port Huron are almost exactly fifty miles each. The amplitude of oscillation was probably twice this or a little more — 100 miles or over — if the Whitley bowlder belt can be relied upon to indicate a readvance from Fort Wayne. The probable cause of the difference in amplitude east and west of Fort Wayne will be discussed later on.

On the whole, the character of the oscillation as one that was always accompanied by a readvance after recession seems to be well established by several different lines of evidence and by several of the most experienced observers.

THE PROBABLE RATE OF ICE-SHEET MOTION.

The great ice-cap of Greenland bears a closer analogy to our own Pleistocene ice-sheet than any other ice mass yet studied. The observations of Peary, Chamberlin, Salisbury, and others throw no uncertain light on the problems of ice-sheet motion as there exhibited. On this point Professor Chamberlin says:

> Lieutenant Peary has commenced a series of observations upon the movements of glaciers of the Inglefield Gulf region, both by instruments and by photographs taken at intervals. He found the daily movement of the Bowdoin glacier, the most active in the immediate vicinity of his headquarters, during the month of July to be four-tenths of a foot at the slowest point, and 2.78 feet at the fastest point, near the center, with an average of 1.89 for the whole.[1]
>
> The movement of the majority of the glaciers in that region is very much slower; indeed, in most cases it is obviously exceedingly slow. Many of the ordinary signs of movement are absent. In front of the Fan glacier there are cones of granular ice brought down by the surface streams, and also embankments of old snow, soiled, granulated, and half solidified into ice, as though at least a year old, all of which lie banked against the terminal face of the glacier without any indication of movement on its part since their formation. As these lean against the face to heights of thirty or forty feet at least, it is obvious that there had been no melting of the base of the extremity to counteract the effects of advance. Phenomena of similar import were observed in several other glaciers. The very firm impression was given by such physical signs that the average rate of movement of the glaciers of the region is very slow. At the head of the gulf are a few glaciers which produce large icebergs and which must be notable exceptions to the prevailing slowness of motion.[2]

[1] According to Professor Chamberlin (JOUR. GEOL., Vol. V, No. 3, 1897, pp. 229–232), the Bowdoin glacier is six or eight miles long, about two miles wide in its lower part and descends between 2000 and 3000 feet. After its separation from the ice-cap by a somewhat steep fall, the Bowdoin glacier becomes essentially Alpine in type. Hence it does not furnish a criterion that can be applied to the ice-cap itself. Slow as is the advance of the Bowdoin glacier, it is probably much faster than that of the edge of the main ice-cap.

[2] Recent Studies in Greenland, Bull. G. S. A., Vol. VI, 1895, pp. 216–217.

Again, discussing glacial motion more broadly, Professor Chamberlin says, referring to Greenland:

No average measurements, nor anything approaching to average measurements, have been made. The high rates of movement of the Jacobshaven glacier, as given by Helland, and of the Great Karajak glacier, as given by Drygalski, and other similar measurements, are not at all questioned, but these are quite exceptional, and almost as far as possible from being representative. They exhibit extraordinary movements through deep constricted straits, where the ice is forced by the vast accumulations of great areas in the rear, and where the warm season appears to exert its earliest and greatest effects. The amount of ice discharged in the form of bergs from these two glaciers is very much greater than from any other known points on the ice-front of Greenland. It is perfectly obvious that the average border of the Greenland ice-sheet does not move at a rate even distantly approximating that of these two straits. If it did so, the whole coast of Greenland must be overwhelmed almost immediately, because the competency of the summer heat of that region to hold back the edge of the ice by melting is very slight. Drygalski estimated the annual surface melting at seven feet. Even this is much greater than the annual surface melting of the Inglefield Gulf region, judged by that of 1894. While estimates are few, and even these may need much qualification, it is nevertheless certain that the average movement of that portion of the border of the Greenland ice-cap which lies upon the land is extremely small. Of that portion which ends in the sea only a small fraction has a high rate of motion, as is shown by the lack of activity in the discharge of icebergs. When it is considered that the land border is very much greater than the sea border, and that of the sea border a portion has a relatively slow movement, it will be evident that the average rate of movement for the border of the great ice-sheet of Greenland cannot be high; and the average rate of this border is the nearest available analogue to the border movement of the still more extended periphery of the ancient American or Laurentide glacier.[1]

There can hardly be a doubt of the great value of the Greenland observations in their bearing on the conditions attending the Laurentide glacier that invaded the United States. It will be observed that most of the measured rates of motion reported by Peary, Chamberlin, and Salisbury are of ice tongues flowing out a few miles from the main cap down valleys generally

[1] The Glacial Lake Agassiz, by WARREN UPHAM. Monograph XXV, U. S. Geol. Survey, 1896. Topic entitled "Alternative Interpretations," by T. C. CHAMBERLIN, pp. 248–249.

steep. None of the measurements are of a broad lobate front such as any one of our great lobes presented south of the lake basins. One would expect the rate of motion to be still slower where it was evenly distributed along a broad front.

There is another character of the borders of the Greenland ice that is a valuable aid in interpreting rates of motion. In all glaciers that move at a relatively rapid rate, as is the case with most Alpine, and fiord, or berg-producing tongues, the ice is cracked and broken deeply, and shows a rough, tempestuous surface with crevasses more or less numerous and deep. Slowly moving glaciers do not show much of this character, but are comparatively solid and smooth down to their ends, and this is the character of nearly all the glaciers that end on land as described and shown in photographic illustrations by Chamberlin and Salisbury.[1]

There is a circumstance connected with some of the moraines in the Cincinnati-Mackinac series which seems to leave little doubt of the slow motion in the great ice-lobes that made them. According to Professor Dryer the front of the Erie ice-lobe at Defiance, Ohio, stood in about sixty feet of water, that being the deepest point of Maumee Lake. But since the recent recognition of the low, faint, water-laid moraines it is found that the front of the ice halted successively at Toledo, Detroit, and Port Huron, in each case standing in about 200 feet of water. The points mentioned mark the apex of the lobe at each halt, and the place of the water-laid moraines and their land-laid extensions seem to show that the ice fitted itself to the valley relief in each case almost as perfectly as it would have done if the water had not been present. This fact throws much valuable light on the condition of the ice when it stood in these positions. Baldwin, Upham, and others have supposed from

[1] Glacial Studies in Greenland, by T. C. Chamberlin, Jour. Geol., Vol. II, Nos. 7 and 8, 1894; Vol. III, Nos. 1, 2, 4, 5, 6, and 7, 1895; Vol. IV, No. 5, 1896. Recent Glacial Studies in Greenland, Bull. G. S. A., Vol. VI, 1895.

The Greenland Expedition of 1895, by R. D. Salisbury, Jour. Geol., Vol. III, No. 8, 1895; Salient Points Concerning the Glacial Geology of North Greenland, Jour. Geol., Vol. IV, No. 7, 1896.

certain evidence they have adduced that lobes ending in glacial lakes broke up like calving fiord tongues and floated away so rapidly as to make their fronts concave.[1] Chamberlin seems to show this effect by two moraines in the basin of Lake Agassiz on his map in Geikie's *Great Ice Age*, 1894 (opposite page 727). Whatever the facts may be for the Lake Agassiz basin, this was certainly not the case with the Huron-Erie lobe. The fact that the ice was able to keep its place in 200 feet of water almost as though no water were present shows (1) that it was not broken and deeply crevassed into loose blocks that might easily float away, but was comparatively solid and compact, proving (2) that its motion must have been of the slow order rather than of the rapid; (3) that its thickness at the edge as it then existed must have been considerably more than 200 feet, probably not less than 300 or 400 feet; (4) that although the front must have been undercut and broken off to some extent by wave action, flotation, and melting in the lake water, this process did not become a factor of sufficient importance to seriously disturb the line of the ice-front as determined by land relief alone. The Saginaw lobe shows the same ability to conform to the land relief while standing in water at the Saginaw moraine over 150 feet deep.[2] I am led to believe, therefore, tentatively, that the motion of the ice-sheet while building the moraines of recession was very slow. That is, it was so slow that the lobes as they crept along remained essentially solid to their extreme edges.

[1] Glacial Lake Agassiz, Monograph, by WARREN UPHAM, Plates XVII and XIX. Pleistocene History of the Champlain Valley, by S. P. BALDWIN, Am. Geol., Vol. XIII March 1894, p. 181.

[2] Nansen, in his "Farthest North," Vol. II, p. 339, describes a glacier-front of this kind in Franz Josef Land in the following terms: "We were soon underneath the glacier, and had to lower our sail and paddle westward along the wall of ice, which was from fifty to sixty feet in height, and on which a landing was impossible. It seemed as if there must be little movement in this glacier; the water had eaten its way deep underneath it at the foot, and there was no noise of falling fragments or the cracking of crevasses to be heard, as there generally is with large glaciers. It was also quite even on the top, and no crevasses were to be seen. Up the entire height of the wall there was stratification, which was unusually marked."

There are some writers who make the whole period of glaciation very short. Mr. Upham believes that Lake Agassiz "endured only a thousand years or less," and he allows "only a few (perhaps four or five) thousand years" for the entire glacial retreat, including the whole Champlain period of submergence and most of the later reëlevation of the land.[1] But it seems to me that both fact and theory as they stand today clearly incline toward a long rather than a short time.[2]

TRANSPORTATION AND DEPOSITION OF ENGLACIAL DRIFT.

If we turn to the best available evidence bearing on the manner and rate of drift transportation by the ice-sheet we meet with facts tending to the same general conclusion, viz., that the building of the moraines was a very slow process. The rate of glacial motion is necessarily a function of the rate of drift deposition. If it is sufficiently clear that the ice motion was very slow we have that much gained towards a determination of the probable rate of moraine building. The other function is the drift load, and we have now to consider what evidence can be brought to bear upon it and also what theoretical considerations indicate as the probable truth.

Here again the Greenland ice-sheet is the closest available analogue and the significance of its indications relating to drift load and deposition are well set forth by Professor Chamberlin. On these points he writes as follows:

That considerable débris is borne in the basal portion of the ice is not questioned; indeed, the term, "englacial drift" was proposed by the present writer in recognition of its importance. Our best evidence of the amount

[1] "View of the Ice age as two Epochs, the Glacial and Champlain." Proc. A. A. A. S., Vol. XLIV, 1895, p. 144. Also Am. Geol., XVI, August 1895, p. 107. For duration of Lake Agassiz see also "Glacial Lake Agassiz," by WARREN UPHAM. Monograph, pp. 241–242.

[2] In studying the history of such a glacier as the Muir of Alaska with its relatively rapid advances and retreats ("Glacier Bay and its Glaciers," by H. F. REID, 16th Ann. Rept. U. S. Geol. Survey; map opposite page 454), and like many of those that calve icebergs in Greenland, it must be remembered that the conditions of their motion are not at all like those of an ice-sheet and that they do not furnish safe criteria for interpreting ice-sheet motion.

and distribution of this is derived from the continental glacier of Greenland. It is there observed that débris prevails in the lower 50 or 75 feet of the ice-sheet, and occasionally reaches up to 100, or perhaps even 150 feet. The amount of this débris, if it were let down directly upon the glacier's bottom by melting in situ without concentration by the forward motion of the ice, would be measured by a very few feet, or by a fraction of a foot. The forward motion of the ice concentrates this at its edge, so that it may there reach, theoretically, any dimension, entirely without regard to its amount in any given vertical section of the ice. The thickness of the deposit formed from the englacial drift is quite as much dependent upon the length of time during which the edge of the ice remains at one line as upon the amount of drift which the ice may carry in any given vertical section. No safe inferences from the thickness of deposits of englacial drift can therefore be drawn with reference to the amount of englacial material present in any given portion of the glacier. If the ice were absolutely stagnant the deposit of englacial drift would be precisely that which was held in the ice above the point of deposit. If there was any forward motion of the ice while it was being melted away, there would necessarily be a concentration. If there be one foot of englacial débris in a given section and the ice moves forward 40 feet while the external heat causes a retreat of 1 foot, the englacial deposit should be 40 feet deep. The thickness of the englacial drift may therefore be quite as much an expression of prolonged time as of a large content of débris within the ice.

Referring to the manner in which the englacial débris becomes at length exposed and deposited Professor Chamberlin, continuing on the next page, says:

Instead of rising toward the surface of the glacier, it is believed, on the basis of observations in Greenland, to pursue a course nearly parallel to the base, on the whole, and to come out at the extremity of the glacier. To some slight extent it may become superglacial by ablation, but only to a limited degree.[1]

Again, describing more specifically the phenomena in Greenland, Professor Chamberlin says:

The débris belts are essentially parallel to the base of the glacier. They are chiefly confined to the lower 50 or 75 feet; sometimes they prevail up to 100 feet and rarely beyond. I think 150 feet might be named as a rather extreme limit. They are more abundant at the sides of the lobes than at the center, a fact that is significant in indicating the introduction of a notable part of the débris after the lobes were formed. In consonance with this the débris appears to be most abundant in the glacier-lobes which descend as cataracts or crowd between closely hugging cliffs. If, standing in front of a

[1] "Glacial Lake Agassiz," Monograph, pp. 249 and 250.

glacial lobe, the dirt bands are traced, many will be found disappearing at the cataracts, or the embossments of the bottom, or at the spurs on the sides.[1]

The general impression produced by such conclusions as these is that an ice-sheet probably carries somewhat less englacial drift than the tongues that, like those of Greenland so far described, branch off from the main sheet and descend several miles and 2000 or 3000 feet down ravines or constricted valleys. The tongues certainly have better opportunities to gather débris than the bottom layers of the main cap. And the force of this impression is greatly increased when we think of an ice-cap that deployed over so smooth a plain as did, for the most part, the Laurentide glacier in the area here considered.

Mr. Upham inclines to the opinion that "englacial drift was carried up through the lower quarter or third part of the ice-sheet, where, as in Manitoba, it was probably a mile thick."[2] But, as Professor Chamberlin has said, there seems to be no reason to suppose that the thickness of the bottom débris-laden layers bears a fixed ratio to the total thickness of the ice. Indeed, from the very fact that the upper part of a glacier moves forward faster than its lower layers, it follows that the bottom layers cannot rise beyond a very limited extent, except by overthrust in consequence of flow over high points or embossments that project upward into the ice. In passing over high obstructions high englacial drift may be introduced. But the amount of such drift appears to be really insignificant, and it even then becomes superglacial only after it has moved with the ice far enough forward into the peripheral zone of ablation to have had all the ice that overlies it melted off, or until it reaches the very edge and is thrust upward over a moraine or other obstruction.

Those who have not seen glaciers have often been much

[1] "Recent Glacial Studies in Greenland," Bull. G. S. A., Vol. VI, 1895, page 205. Contrast with these ideas the opinion of MR. UPHAM, where he says, speaking of the great Leaf Hills moraine in Minnesota, that "perhaps not more than fifty or even twenty-five years [were occupied] for amassing these morainic hills 100 to 350 feet high on a belt 3 to 5 miles wide!" ("Glacial Lake Agassiz," Mon., p. 242).

[2] "Sublacustrine Till," W. UPHAM, Am. Geol., Vol. XVII, June 1896, pp. 374–375.

deceived as to the amount of englacial drift by the highly deceptive appearance of pictures of débris-laden, melting ice-tongues. Chamberlin and Salisbury both draw attention repeatedly to the effect of the spreading of fine dirt so as to blacken the whole ice wall. When small streams of clear water wash this away, or the dark surface has been removed with a pick, comparatively clear ice is seen beneath, and yet some of these layers or thin laminæ which they contain, may be the very ones that were supplying the blackening material. Large masses of englacial drift are rare and their forward motion is extremely slow, certainly much slower than that of the clean ice above, except where they occur, still more rarely, as lenses relatively high up in the glacier so as to have a considerable thickness of clear ice beneath them. In short, it seems to be shown that englacial drift is a far less voluminous constituent of ice-sheets than has been supposed by many. It keeps its importance, however, as almost the only means of drift transportation by continental glaciers like that which invaded the United States. But except under peculiar circumstances the amount in any given section of ice is almost insignificant. When all the circumstances are taken into account it seems probable that the load of débris is as great or greater in the Greenland tongues than it was in the Laurentide lobes in Ohio and Michigan. The coast of Greenland is mountainous. The ice flows out among many nunataks and along the base of high cliffs, and no doubt overrides many knobs and peaks and precipices from all of which it gathers material in such a way as favors its becoming superglacial or englacial. Then, too, the exceedingly rough country is favorable to the production of high overthrusts by which the bottom layers with their débris may assume relatively elevated positions in the ice.

When the ice-front was in Ohio or Michigan there was no chance for the formation of lateral moraines from cliff-fallings, nor of medial moraines from the detritus of nunataks. At that stage of glaciation the field of ice stretched away to the north-northeast without a break, and no land was exposed back of the

edge. In Canada some of the path of the ice was rather rough, but not in any sense comparable in this respect with most of the coast of Greenland, and it was all deeply overridden at the time the ice reached across Lake Huron to points farther south. It follows that substantially all the northern drift of Michigan, Ohio, Indiana and Illinois was carried forward from Canada englacially. But the larger portion of the drift south of the lakes is of local origin, derived from rocks near by. This region, as the last ice-sheet found it, was probably a comparatively smooth drift plain, made so by earlier Pleistocene ice-sheets Almost the only way that local débris could become englacial was by being taken up, absorbed or incorporated directly into the lower layers of the ice as the glacier moved along. Under the great pressure of ice, hundreds or perhaps thousands of feet deep, this process must have become more or less effective. It seems almost certain that substantially all the drift south of the lakes was transported englacially, and in only the lower layers of the ice-sheet. The maximum load which can be carried in the bottom layers of the ice without overthrust cannot exceed a certain amount for a given pressure and rate of glacial flow, and that amount is probably not large. When the bottom layers become overloaded they clog beneath the ice and cease to move, while the cleaner upper ice forms a plane of shear above the clogged layers and overrides them. Professor Salisbury, writing of the glaciers of Greenland, says:

> Professor Russell has called attention to the fact that the movement of ice is influenced by the amount of débris which it carries. This doctrine finds abundant confirmation in the north. The lower part of the ice, which is well charged with débris, or altogether full of it, seems to virtually lose its motion and to become the bed over which the upper ice passes. It is not possible to say that its motion is absolutely lost, but many phenomena seem to make it certain that the upper portion of the ice of a glacier passes over the lower débris-charged portion in the same way that it passes over a rock bed. The lower part of the ice in such cases becomes virtually an ice conglomerate, the mobility of which is certainly slight.[1]

[1] "Salient Points Concerning the Glacial Geology of North Greenland," by R D. SALISBURY. JOUR. GEOL., Vol. IV, No. 7, pp. 800–801.

It appears to be a plain inference, even in the case of the extremely slow motion of the Greenland cap, that however slowly the upper layers of the ice move, the débris-laden bottom layers move still more slowly. Even in a fiord tongue which moves 50 or 100 feet a day, if the ice is 1000 to 1500 feet or more deep the extreme bottom layers may move quite slowly.

The principles involved in basal clogging have been well brought out by Professor I. C. Russell. He reduces them to this proposition: "The rate of flow of glacial ice, under given conditions, will depend upon the percentage of débris commingled with it, and be least where the percentage is greatest."[1] For our present purpose this law may be advantageously restated in terms of drift transportation and deposition rather than ice-motion, thus: Whether the basal layers of a glacier will absorb or deposit débris at a given place or pass over without doing either, depends on their carrying an underload, an overload, or just an even full load at the existing velocity and pressure.

Under deep ice, however, the building up of ridges or prominences like terminal moraines, by the clogging of débris-laden bottom layers, would seem to be impossible, because the tendency there is to wear down and abrade every prominence of the land that is overridden. Clogging under deep ice probably occurs to some extent, but only by the shearing off of thin bottom layers which do not remain as subglacial prominences. Hollows of the land surface would tend to be filled up by clogging, and a mass of débris once dropped in such a place would tend to stay there unless the peculiar and rare conditions which lead the ice to scoop out basins came into play. While the general truth of Professor Russell's proposition is plain, and the principle stated is one of great value, it may be doubted whether it can have such a function as he supposes when he suggests that it was the determining cause of the moraines of recession and their peculiar distribution.[2]

[1] "The Influence of Débris on the Flow of Glaciers." JOUR. GEOL., Vol. III, No. 7, pp. 823–832.

[2] In a footnote to his article (page 831) Professor Russell makes the following

The great Malaspina glacier of Alaska, so well described by Professor Russell, belongs to the Piedmont type, and is probably

suggestion: "That a series of terminal moraines in a formerly glaciated valley, or a similar succession of ridges left by a continental glacier, are not necessarily evidence of repeated climatic oscillations, but may have been formed during a uniform and continuous meteorological change favorable to glacial recession. That is, a débris-charged glacier may retreat for a time, then halt and again retreat, owing to its terminus becoming congested with foreign material, in response to a climatic change which would cause a glacier composed of clear ice to recede continuously and without halts."

It is hard to see how clogging of the lower layers could have the effect of building a ridge like a terminal moraine anywhere except at or very near the edge of the ice-sheet; and it seems certain also that the building of a great moraine must have required a relatively long duration of time—much longer than the building of the flat intermorainic plains of till. But under a uniform change of climate, as supposed by Professor Russell, it seems impossible to allow much more time for the building of a moraine than would be taken by a clear-ice glacier to retreat over an interval equal to the width of the moraine unless the formation of the moraine is supposed to begin under deep ice far back—at least several miles back—from the edge of the lobe. When the front of the Maumee ice lobe was at Fort Wayne the ice was probably 400 or 500 feet thick within a mile or two back from the edge, and its thickness increased to the northeast. From Fort Wayne to Port Huron there are five moraines in series with four intervals of about fifty miles each, and with wide till plains intervening. When the ice-front was just east of the Fort Wayne moraine, did basal clogging begin then at Defiance, forty-five miles back under the deep ice, or did the ice-front retreat from Fort Wayne to Defiance without clogging only to begin it again at the latter place? If the former, then we must set aside the law of heavy abrasion on subglacial prominences under deep ice. If the latter, then, as already pointed out, the time allotted for the building of the moraine is little if any longer than that which would be taken by a clear-ice glacier to retreat over a distance equal to the width of the moraine.

The Port Huron-Saginaw moraine is clearly traceable as a distinct individual from the highlands south of Georgian Bay, where it is about 1000 feet above the lake, descending to lake level at Port Huron, rising thence 300 feet to Ubly on the "thumb" of Michigan, descending again to lake level at Saginaw, rising again towards the northeast to the Au Sable River, and thence northwest nearly as far as Petoskey, where it is again about 1000 feet above the lake—a distance of over 400 miles. It seems hard to account for such a moraine by clogging alone, and for a series of them, the existence of which is a matter of simple inference from the facts now at hand, the difficulty becomes much greater. Speaking of the terminal moraines of the United States, Professor Chamberlin says: "Some of these have been traced several hundred miles in individual distinctness, and, by fair correlation, may be assumed to have been identified for a thousand miles or more." (GEIKIE'S "Great Ice Age," 1894. p. 740.)

But even if basal clogging in itself could produce moraines, that process taken alone could hardly be the cause of such a marked and widespread periodicity in the phenomena. The continuity and great length of individual moraines shows that the periodic rhythm of the oscillations affected wide areas; indeed, there lacks but little to

the best modern example of it.[1] But this glacier is the dumping ground of hundreds of Alpine glaciers of the most pronounced type, all descending steep, short slopes from high mountains, and carrying heavy loads of débris—superglacial loads as medial and marginal moraines, as well as heavy englacial loads in their bottom layers. Contrasted with this the Laurentide glacier had no Alpine feeders whatever. Substantially all that it accomplished in the transportation and deposition of drift was done by its bottom layers in englacial fashion. The Malaspina apparently suggests nothing that would controvert the general conclusions drawn from other sources. For its most characteristic features are exceptional, and obviously do not apply to the Laurentide ice-sheet nor to ice-sheets in general.[2]

THE PROBABLE DURATION OF THE PERIODS OF GLACIAL OSCILLATION.

A little examination will show that no short period, such as 35, 100, or even 300 years will suffice for the building of the moraines. From Fort Wayne to Port Huron there are five moraines with four intervals of almost exactly fifty miles each. These constitute perhaps the simplest group in the whole moraine series. They have the widest and most regular intervals and some of them, when not too deeply water-laid, are the very best types of the structure characterizing deposition at a climax of readvance. The intervals are so wide, and the valleys in which

prove that it was of continental extent. From present indications it would seem almost certain that future investigations will establish this as a fact. But even supposing moraines to be formed sometimes by basal clogging, what could be the cause of such widespread periodic clogging if not climate?

[1] "Mt. St. Elias and its Glaciers," Am. Jour. Sci., Vol. XLIII, March 1892, pp. 169–182; "Malaspina Glacier," Jour. Geol., Vol. I, No. 3, pp. 219–245.

[2] Mr. Upham has recently enlarged and elaborated Professor Russell's suggestion, but apparently without throwing any new light on the obscure processes involved. (Am. Geol., Vol. XIX, June 1897.) He also endeavors to enforce the Malaspina glacier, which is a perfect example of the Piedmont type, as a criterion for interpreting the Laurentide ice-sheet or continental glacier. In this effort he even goes so far as to call the Malaspina glacier an ice-sheet—an application of the term which is clearly erroneous and misleading.

the broad Huron and later Erie-Huron ice-lobes advanced are so wide and smooth that the circumstances favoring simplicity were at a maximum.

Suppose it took the ice-front thirty-five years to retreat from the Fort Wayne to the Defiance moraine, receding at a uniform rate. That would be a little over twenty and a half feet a day. But this allows no time for retreat beyond Defiance, nor for the halt at the warm climax of retreat and the building of a moraine there of equal magnitude with that now seen at Defiance, nor for the readvance to Defiance, nor finally for the building of the Defiance moraine. If the Defiance moraine was built after a readvance and if the nature of the oscillation was such as shown in Fig. 1, then the time taken for the retreat from Fort Wayne to Defiance must have been only a fraction of the whole period of oscillation. We may measure the period of oscillation between the crests of the moraines, including always the destroyed moraine of the warm climax. We may assume further that the readvance is at least half of the previous retreat, and in this case the moraine of the warm climax next after the Fort Wayne moraine would be built at some point near Toledo and after it was finished the ice-front would readvance to Defiance. Then the first half of the period of oscillation would be measured between the crests of the Fort Wayne and Toledo moraines, and the second half between the crests of the Toledo and Defiance moraines. The two middle points of oscillation would then be half way between Fort Wayne and Toledo and half way between Toledo and Defiance. The first of these would be about at Defiance. On this basis the retreat from the crest of the Fort Wayne moraine to the middle point at Defiance would take one-fourth of the time of the whole oscillation and this includes half of the time of the building of the Fort Wayne moraine. On the basis of thirty-five years for the whole, this one-fourth part would occupy only about eight and three-fourths years, and surely half of this time would have to be taken to build half of the Fort Wayne moraine, and that would leave only four and three-eighths years for the ice-front to retreat fifty miles. The rate of retreat

would then average about 164 feet a day. And further, this retreat would have to take place in the face of the continual advance of the ice, so that the ice would have to melt back probably considerably more than 164 feet a day. Such a conclusion is manifestly absurd and its absurdity is only increased when we reflect that this is the average per day for the whole year. During the winter months there must have been not only no great amount of melting, but more or less readvance because melting ceased; and it is probably true that for some months in the spring and fall the forces of advance and retreat were about at a balance. Only for three or four months in summer would the forces of retreat be effective, so that substantially the whole annual retreat would have to take place during the summer and the rate of retreat would have to be at least four or five times the daily average for the whole year, or 700 or 800 feet or more per day. It does not help the matter much to change the period to 100 or even 300 years. For it would still be necessary to postulate a high rate of retreat—seventy or eighty feet per day during the effective melting season. If the period were 3000 years the rate would still be seven or eight feet a day at that season. With the period at 6000 years the rate would be three and a half to four feet a day, and at 12,000 years one and three-fourths to two feet a day.

We may suppose, if we choose, that at every turn of retreat the ice-sheet became completely disintegrated and broken up, at least over a wide marginal belt, on account of the suddenness and intensity of the increased warmth. But such a supposition savors of catastrophism and does not seem to be in the line of probable truth. The equilibrium between glacial accumulation and ablation must have been a very delicate one. There could be no wide departure from a balance of forces without a corresponding great change in the extent of the ice-sheet. Surely the climatic conditions which permitted the ice-front to stand for a long time at Fort Wayne were not greatly different from those that permitted it to stand at Defiance or at Toledo. There is no need of supposing that sudden or violent climatic changes produced

the oscillations. There is nothing in the phenomena of the drift that requires it, nor has anything been discovered in the behavior of the Greenland ice-sheet that suggests it. The summers were seasons of melting during the phase of advance as well as during that of retreat, and it may be doubted whether the most skillful observer could have detected any difference in the summers of the two phases unless he had made the most refined gauge measurements on the volume of the water discharged. Whether the ice-front would advance a little or recede a little or remain stationary during a long period of years was a matter of the utmost delicacy of adjustment. I doubt whether the average annual temperature for a period of years need differ more than two or three degrees to determine whether the ice-front shall stand at Fort Wayne or at Defiance.

Again, there seems every reason to suppose that the general advance of the ice-sheet was after the same manner as the retreat, only that the oscillations were reversed, and that it required the same duration of time. From the halt at Defiance the ice would retreat to Toledo, and then readvance to Fort Wayne, and so on. If this is a true assumption, then it would require us to suppose that the ice-sheet must be able to advance from Toledo to Fort Wayne in the same time, and hence at the same rate, as it is supposed to retreat over the same interval during the general recession. But it is manifestly impossible to suppose that the ice advanced at a rate of anything like 1000 or even 100 feet a day. The great wide lobe that advanced up the Maumee valley is not to be compared with the Muir, or the Karajak glacier, but rather with some part of the Greenland ice-cap that ends on land. It was not breaking off and floating away as bergs. It seems certain that its motion must have been very slow, probably not over two to five feet a day, even at the maximum.

But if it seems necessary to put the period of oscillation at 3000 years or more, it becomes a matter of comparatively small importance whether it be a little more or less. We have no means of knowing just what it was, but if 3000 years seems to be an extreme minimum and 6000 years seems better, there is no pos-

sibility of drawing the line just there and saying that it could not have been 10,000 years or even more. At the present day the combined weight of the facts, theories and analogies available to us seems to me to lean toward the conclusion that an oscillation period of between 5000 and 10,000 years would be the most satisfactory. If we take the Fort Wayne moraine to be five miles wide and the period of oscillation to be 5000 years, and if we suppose the period to be divided in two halves equal in time, one of advance to Fort Wayne over a space of fifty miles and the other of retreat from Fort Wayne over a space of 100 miles, then we may say in round numbers that it took 700 or 800 years to build the Fort Wayne moraine. If we take the period of oscillation to be 10,000 years, then it took twice as long.

THE SUPERPOSITION OF THE OSCILLATIONS UPON A GREATER AND MUCH SLOWER CLIMATIC VARIATION.

That there was a periodic oscillation of the ice-front of some kind or other needs no better proof than the simple fact of the existence of the moraine series itself. We have seen that by its influence upon climate precession would tend to produce a to and fro oscillation of the ice-front. We have seen also that there is a considerable amount of reliable evidence showing that the oscillations which took place did, in fact, have the character ascribed to precession. But if terrestrial climate had suffered no change from any other cause than that which produced the oscillations, then the ice-front would have gone on playing back and forth for an indefinite time over the same narrow strip of ground. But the moraines are distributed in a great series from south to north with intervals between them that are remarkable for their regularity, when due allowance is made for the influence of topography. This arrangement seems to be explicable only on the supposition that besides the oscillations there was another greater, slower change of climate in progress—many times longer in duration than the period of oscillation. Whatever their cause, the oscillations were obviously superposed upon this

greater, slower climatic change. After the grand climax of advance, when the ice of this epoch reached its farthest point south, the long retreat began and the oscillations that made the moraines of recession went on round after round during the slow progress or the greater change. This is a truth that stands out clearly on the face of the larger facts and is entirely independent of all theories as to the cause of the oscillations or of the greater change itself. Here again the moraines of recession, by their arrangement, and by the regularity of their intervals, help us to a partial insight into the nature of this greater change—the real cause of the Ice age. Not that they show us the whole cause fully and clearly, for they do not. But they show us enough of its real nature to enable us to eliminate several hypotheses that have been suggested, and so to narrow the range of discussion. The cause of the greater change must have been of an astronomical nature, and there is apparently no alternative.

In order to see the full import of the facts we must see just how the oscillation is related to the greater change. If the oscillations were regular (either with equal time intervals, or with time intervals that varied progressively at a uniform rate) and the greater change also regular (uniform or varying at a uniform rate) then the moraine series would tend to be regular, but if either one or both of the changes were irregular, then the moraine series would be irregular. To get a regular moraine series out of a combination in which either factor was irregular would be accidental, and an assumption that such a cause has produced the moraine series would be gratuitous and without reasonable foundation.

A careful analysis of the effect of topography in causing irregularities in the moraine series seems to show that the intermorainic intervals are not uniform, but increase from south to north. By reference to the map it will be seen that from the first moraine back to the ninth, or Fort Wayne moraine, the intervals are shorter than from Fort Wayne northward. The effect of topography can be best understood by considering the glacier in its advancing phase.

When the ice-front was at the Hagenville (15th) and Alcona (14th) moraines, the apex of its lobe in the Huron basin was in the present lake bed, and so cannot now be exactly located nor measured. But at the next halt the ice-front stood at the Port Huron-Saginaw moraine (13th). This is the first one now fully recorded on land. At that halt the ice was held back by the highlands south of Georgian Bay in Ontario, and by those southeast of Petoskey in Michigan, and it was also held back about fifty miles by the "thumb" of Michigan. With further advances the separated Saginaw and Huron lobes moved forward nearly equally at first, but soon the Saginaw lobe met higher ground, and slowed its pace, while the Huron lobe moved on more rapidly and met and blended with the Erie lobe coming up the Erie basin from the northeast, and the two advanced as one lobe up the Maumee valley. The ice clogged more and more against the high ground in southeastern Michigan, and began the building of a great interlobate moraine upon it. This obstructed the advance of the Maumee lobe pretty effectually on the northwest side, while the high ground along the south side of the Erie basin did not allow of much expansion on that side either. Hence the advance was mainly up the wide flat Maumee valley until Fort Wayne was reached. At this point there came an important change. The ice-front had almost reached the flat rim of the Erie basin along that part of the front line which extends from Fort Wayne eastward about 140 miles, nearly to Mansfield, Ohio—to the east side of the head of the Sciota valley. The subsequent advances found ample room for expansion in the most advantageous way; that is, in a southerly direction and down grade. The ice soon began advancing down the Wabash and White River valleys in Indiana, and down the Miami and Sciota valleys in Ohio. Besides, the Maumee lobe had now pushed so far ahead of the Saginaw that the obstruction on its northwest side in Indiana had been somewhat relieved. But before becoming distinctly segregated into four sub-lobes, the ice advanced for a few steps very evenly over the level summit plateau, forming the remarkably regular and concentric series of moraines south of Fort Wayne

and extending over into Ohio. At the sixth and fifth moraines the ice-front began to push slightly forward down the Miami valley, but the lobe did not become distinct until the fourth moraine. From that to the first moraine the Miami lobe developed more and more individuality. The first four moraines mark the fully developed lobe and the circumstances under which they were made probably accounts for the smallness of two of their intervals—eight and twelve miles between the second and third and the third and fourth respectively. The Miami was the smallest and narrowest of the four valleys and hence its ice-lobe was more cramped than the others. Besides, there was no such concentration of advance in the Miami valley as there had been before in the Maumee. The pressure was relieved by the other three lobes, while from Detroit and Cleveland to Fort Wayne the large Erie-Huron lobe was cramped by highlands on its sides and hence pushed forward in a comparatively long, sharp point.

In this discussion of the intervals we have followed the ice in its advancing phase. We have only to reverse the order of events to see that the influence of topography was substantially the same during the retreat.

This, as it seems to me, is the true explanation of the variations of the intermorainic interval, and it indicates that the narrow intervals which prevail from the first to the ninth moraines are not out of harmony with the wider intervals from the ninth to the thirteenth. The shorter intervals of these moraines do not indicate, as might be supposed, a radical difference in climatic conditions, nor of amplitude of oscillation, nor, possibly, of the rate of the general retreat, but mainly the influence of topography.

If the moraines showed nothing further it would seem clear that the rate of the main retreat had been perfectly uniform, or at least very nearly so. But if we turn to northern Michigan and compare the intervals of four moraines there with the four south of Fort Wayne, an increase of the interval northward seems to be suggested. South and southwest of Fort Wayne four parallel moraines (the sixth to the ninth) lie within a space

of forty-five miles. They were formed at the broad apex of the Maumee lobe expanding on a nearly level plain. In the north there are four parallel moraines (the twelfth to the fifteenth) also in a space of forty-five miles on a line running southwest from Rogers City past Gaylord. These moraines are banked up against the northeast face of the highlands and mark a great reëntrant angle of the ice-front. The fifteenth is 800 or 900 feet lower than the twelfth, while the ninth near Fort Wayne (on a line running southwest from Paulding, Ohio) is only about 100 feet below the sixth. At present we have no measure of the intervals in the north except on this steep slope. It seems plain, however, that if these four moraines had been laid down on a level plain without being banked up against the highlands the normal interval would have been considerably greater than it is. On the other hand, near Fort Wayne it seems clear that if the highlands of northeastern Ohio and western Pennsylvania and New York had been absent and a level plain there instead, so that the expansion could have been distributed evenly along the edge, the normal interval would have been somewhat less than it is.

These facts seem to show that while the oscillations were going on, probably at a substantially regular rate, the main climatic amelioration and its resulting glacial retreat was also going on, not uniformly, but at a progressively increasing rate. From the first (or second) moraine near Cincinnati, where the great advance of this epoch had stopped and the great retreat begun, the ice-front retreated at first very slowly, but faster and faster as the front receded northward. Here again the character of the simple harmonic motion seems to be revealed as the probable manner of the varying rate of retreat. And this gives a decidedly astronomical quality to the cause. Whether the cause was due to some greater variation like precession, or to some slow orbital change, either of eccentricity or of magnitude affecting the distance of the earth from the sun independently of eccentricity, it may at least be said that any variation of climate that can be so represented must spring from a cause which

proceeds in a great curve, and if glacial epochs are periodic, as they may be, then the variation is expressed by a closed curve, either circular or elliptical.

The manner of retreat under such a combination of forces may be represented graphically with approximate accuracy as follows: Assuming the oscillation to be superposed upon a greater amelioration having a uniform rate, the resulting path would be an epicyclic curve. If the recession took the form of retreats and halts without readvances the curve would come to a point at the moraines as in Fig. 4, A, and the moraines would have cross sections, under the simplest conditions of formation, like that shown in the figure. With readvances the curve would be a looping epicycle as in Fig. 4, B, (*a*) and (*b*), and if the readvances covered more than half of each preceding space of retreat the loops would overlap as in Fig. 4, B, (*c*). In both free and overlapping loops, the forms of the moraines would be as shown in Fig. 1 at A, and in Fig. 4, B, and C. As we have seen, this last appears to have been the actual manner of retreat, at least in Ohio, Indiana, and Michigan. This is shown in Fig. 4, B, (*c*). If the greater climatic variation is truly represented by a simple harmonic motion, then the overlapping of the loops was most extensive near Cincinnati, and decreased going northward. This order of retreat is represented approximately by Fig. 4, C. The facts seem to favor this method of interpretation quite strongly, but it is not necessary to pursue the theoretical aspect of the problem further here. It is suggested in this paper that precession of the equinoxes may have been the cause of the secondary climatic oscillations which produced the moraines of recession. But no statement, nor even a definite opinion, is ventured as to the cause of the greater, primary variation of climate which brought on the Ice age itself, except that it was of an astronomical nature. It may be added, however, that the astronomical theory of Croll even as modified and reënforced by Ball, is thought not to afford an adequate or satisfactory explanation. As to those other various hypotheses which postulate purely terrestrial causes, such as the displacement of the

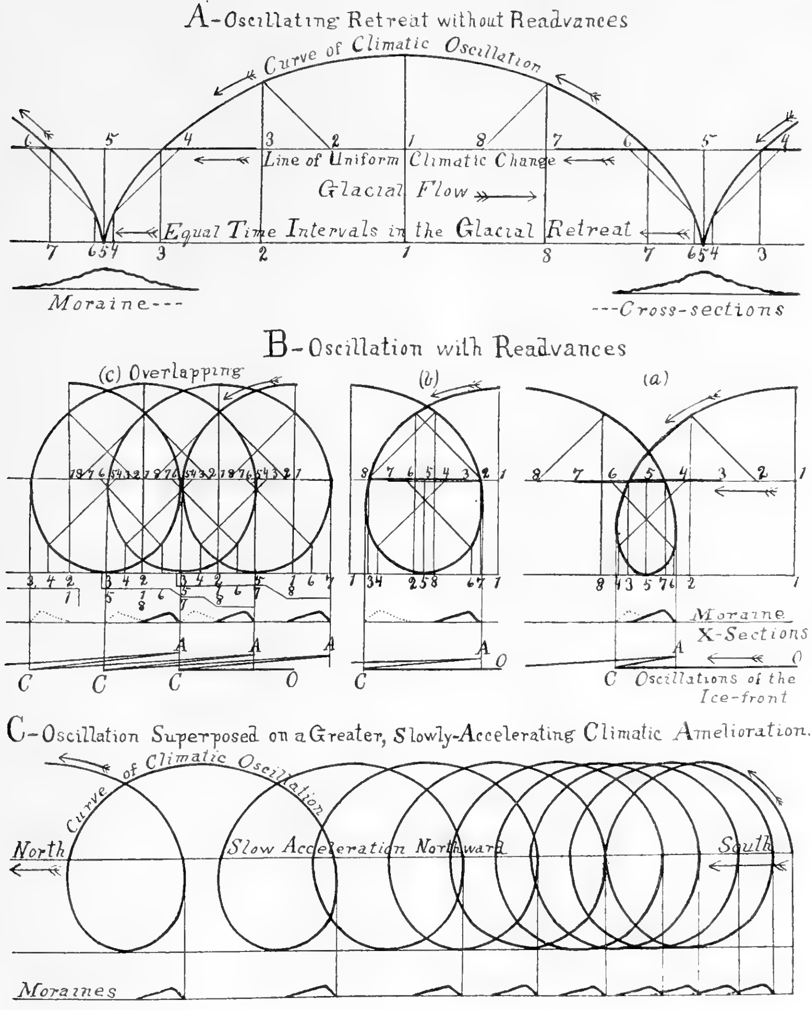

FIG. 4. Showing combinations of the period oscillation with the greater climatic change.

Gulf Stream by the submergence of the Isthmus of Panama or by the elevation of a supposed Antillean continent, or those that rely upon mere epeirogenic uplift in the north, they have no sort of intelligible relation to the characters revealed by the drift. In fact they appear to fall so far short of explaining these characters that there seems to be no longer a hope of gaining any real advantage from their consideration.

SUMMARY.

1. Between Cincinnati and Mackinac the Wisconsin drift formation has fifteen terminal moraines which form a consecutive series marking the retreat of the last ice-sheet; and there are three more farther north probably belonging to the same set. The series seems to be complete and is believed to constitute the simplest and most perfect known.

2. Making due allowance for the influence of topography, it appears that the intervals between the members of the series are remarkably regular, suggesting periodic halts or oscillations of the retreating ice-front, which appear to be attributable only to a periodic change of climate. But, excepting the annual period and a thirty-five-year period deduced by Forel and others from glacial and meteorological observations, the only periodic change of climate known is that due to the precession of the equinoxes with a period averaging 21,000 years and a minimum of 10,500.

3. A study of the forms of the moraines where they were made under the simplest conditions shows that they were always made at the climax of a readvance. In one instance at least the readvance appears to have covered more than half of the space of the previous retreat. Theoretically, the influence of precession on climate would cause a to and fro oscillation of the ice-front after the manner of a simple harmonic, and this superposed upon a greater and slower change, would produce an oscillating retreat with minor periodic readvances. This appears in fact to have been the manner of retreat during the formation of the moraine series, for those formed under the simplest con-

ditions have their crests forward; they have relatively short, steep front slopes and long gentle back slopes.

4. In attempting to deduce a period of oscillation from the study of existing things, the present ice-cap of Greenland was taken as the closest analogue for interpreting the drift of the Laurentide ice-sheet, and the chief reliance is placed in the observations of Professors Chamberlin and Salisbury. From these the conclusion is reached that the frontal edges of the great ice lobes that made the moraines of recession moved only very slowly, so slowly as to be in substantial accord with a period of oscillation equal to the minimum value of the precessional period. A period of between 5000 and 10,000 years, however, would seem to accord most closely with the phenomena. From Fort Wayne to Port Huron there are five moraines with four intervals of about fifty miles each. On this basis the Fort Wayne moraine with a width of five miles would have required something between 700 and 1600 years for its making.

5. The regularity of the oscillation and also of the greater climatic change upon which it was superposed both point clearly to astronomical causes. The periodic oscillation may have been due to precession, but no opinion is ventured as to the cause of the greater change. On this basis then, it took the ice-front 75,000 to 150,000 years to retreat from Cincinnati to Mackinac, and the whole glacial epoch lasted at least 150,000 years and possibly 300,000 or more. And if glacial epochs are periodic, as they may possibly be, then this period is only a fraction of the great cycle of climatic change.

FRANK BURSLEY TAYLOR.

THE ERUPTIVE ROCKS OF MEXICO.

PART III of the recently published *Bosquejo Geológico de México* consists of a study by Ezequiel Ordoñez of the eruptive rocks of Mexico.[1] This may be regarded as the most complete and satisfactory summary of the present state of knowledge of this subject which has yet been published.

Humboldt's *Essay on New Spain* contains many observations on the rocks of the silver-bearing regions of Mexico which are made with great accuracy and fullness of detail. But the science of petrography has made many advances since Humboldt's day. It is no longer sufficient to describe rocks as primitive schists and porphyries nor can altered andesites and tuffs be disposed of as graywackes. These terms are, however, an improvement on *saxum metalliferum*, the name by which many of the rocks were earlier known. Modern geologists, moreover, can hardly agree with the great *savant* in his conclusion that the richness of veins is entirely independent of the nature of the rocks which the veins traverse. The great similarity found among the rocks of the silver-bearing regions of Mexico and their resemblance to those of Nevada and Germany in which similar veins occur, indicates that a definite relation probably exists between rock and vein.

Humboldt's work, however, remains about the only authoritative one on the rocks of Mexico as a whole, which can be consulted. The names which he applied to the rocks and the opinions which he expressed regarding their origin will be found to be those prevailing in Mexico today. Since the publication of his work studies of single rocks or of limited regions have been published, but little, if any, attempt has been made to correlate observations. There is room, therefore, for a comprehensive study of the kind made by Señor Ordoñez.

[1] *Boletin del Institute Geológico de México*, Nums. 4, 5, y 6, Mexico, 1897.

In his paper the rocks are described in terms of modern petrography and with as much detail as the plan of the sketch permits. This plan he states to be an endeavor to give some idea of the petrographic provinces of the country, indicating for each one of them the predominating species, without entering into minute details concerning the extent of each. Commencing with the pre-Cretaceous rocks, the granites, pegmatites, granulites, syenites, and diorites of this age are described in order in their respective provinces. The post-Cretaceous rocks are discussed next, beginning with the granites and passing on in order through the granulites, diorites, diabases, andesites, dacites and rhyolites. Then are taken up what are called the andesites of the second invasion, which were produced by the volcanic eruptions which began near the end of the Tertiary period. Finally the labradorites and basalts which largely characterize the latest eruptions are considered. Of especial interest is the account given of the rocks of the great silver-bearing regions of Zacatecas, Guanajuato and Pachuca, regions which though widely separated, the author finds to present remarkable uniformity as to kinds of rock and circumstances of outflow.

The work is marred by some errors, such as calling hypersthene a monoclinic pyroxene (p. 264), and the indiscriminate use of the terms amphibole and hornblende. The punctuation and paragraphing also admit of much improvement. The character of the work is as a whole, however, so admirable, that I have thought that to give a résumé of it by means of a translation of extracts would assure a wider circulation to some of the facts enunciated by Señor Ordoñez than they would perhaps otherwise attain. Of such extracts the remainder of this paper is made up.

The first indication of the part of the American continent which forms the country of Mexico, was given in Palæozoic time by the emergence of a narrow, elongated backbone which uniting with the beginnings of the Rocky Mountains to the north and of the Andes to the south constituted the foundation

of the orographic system known as the Cordillera of the Andes It is in the part of Mexico known by the name of the Western Sierra Madre that we may expect to find the principal types of ancient eruptive rocks, associated as a rule with crystalline schists and some of the earliest sedimentary rocks. The Sierra Madre extends along the Pacific coast in a general southeast-northwest direction. The western slopes, generally descending rapidly to the coast, present a notable contrast to those of the east, where numerous spurs or secondary sierras serve to support the extensive plateau of the Mesa Central. It was along the eastern slopes that the eruptive movements which in epochs later than the Cretaceous added to the relief of the Sierra Madre, chiefly occurred. Here may be seen the whole series of modern eruptive rocks, from the granites with which the eruptions clearly began, to the basalts of Quaternary time.

Considering first, then, the pre-Cretaceous rocks, we find them consisting chiefly of granites. These probably make up a large part of the mountains along the western coast of the Peninsula of Lower California, but of their exact distribution we know as yet little. In the region of Hermosillo, Sonora, in the district of Moctezuma, granite, crossed by dikes of pegmatite, occupies great tracts of country. In the district of Altar syenites and diorites replace the granite. In the region south of the state of Puebla in the districts of Chiautla and Matamoros micaceous or amphibolic granites are found passing over to gneiss or green schists. The granites are interrupted frequently by modern eruptive rocks, chiefly rhyolites and andesites, or even by stratified rocks, generally Cretaceous. In the state of Jalisco in the canton of Mascota and along the slopes of the Sierra toward the Pacific, the group of mountains of Desmoronado is formed of granites associated with quartzites and other metamorphic schists. In the central and western parts of the state of Oaxaca may be seen an extensive formation of granites and diorites, covered sometimes by breccias and modern quartzose conglomerates. These ancient masses, chiefly granites, may be followed, although interrupted by modern eruptive and sedi-

mentary rocks, nearly to the coast of the Pacific and the Isthmus of Tehauntepec.

By far the larger number of the eruptive rocks of Mexico are, however, of post-Cretaceous origin. Among the rocks which began this prolonged eruptive epoch, granites and granulites predominate, syenites are rare, andesitic diorites are abundant, and diabases sometimes occur. The different varieties, however, pass from one to another by insensible gradations, and frequently exhibit as well an ophitic or trachytic structure which leads them to resemble the true porphyrites and andesites. The frequent recurrence of these phenomena serves as a corroboration of Iddings' theory of the differentiation of magmas. The post-Cretaceous eruptive rocks which approximate in structure most nearly to those of pre-Cretaceous age, occur chiefly in the central regions of the northern and northeastern portions of the country, and are usually associated with Cretaceous limestones. The granulitic structure is that which predominates, but it may be modified to that of the granites, or even descend through the micro-granulites to the orthophyres and rhyolites.

The rocks which come after the granites have usually been known in Mexico as greenstones or green porphyries on account of their characteristic color and porphyritic appearance. To these rocks great interest has long been attached since they lodge the most important metalliferous veins of the country. A chart showing the mines of Mexico well indicates the distribution of these rocks. Each metalliferous district presents in the mass of its rocks a similar series of eruptions, thus indicating a certain contemporaneity and analogy of circumstances of outflow. The three types of rocks found in these districts in the order of their appearance are: (*a*) andesites and green dacites, (*b*) rhyolites, and (*c*) labradorites and basalts.

Those of the first type have already been referred to as greenstones. They may also be described as andesitic porphyrites, chiefly of hornblende, and orthophyres, while some more nearly resemble the amphibole and pyroxene-andesites. All present similarities to the rocks described by von Richthofen

under the general name of propylites, which are well known in Hungary, Transylvania, Nevada, and from some South American localities. They present various aspects of the trachytic and trachyto-porphyritic structure, a different quantity and development of the elements of the first generation sometimes causing the microlitic magma to predominate over the amorphous. An idea of the various aspects which these rocks present can be given by mentioning some from different localities. Commencing with the dacitic types, one may note the rock which occurs at various points in the mining district of Parral, in the state of Chihuahua. It is dark green to dull green in color, and contains scattered crystals of transparent feldspar, together with hornblende that to the naked eye appears to be of a dark green color, and lamellæ of dark green mica. The magma is of a character in part microfelsitic and in part microlitic, with disseminated particles of yellowish green hornblende, which is the mineral which gives to the rock its color. The crystals of hornblende are in part decomposed and do not always preserve their sections. This alteration, either central or peripheral, consists of a transformation to calcite, chlorite and sometimes to epidote.

To judge by the free quartz which it sometimes contains, this rock bears some similarity to the felso-dacites of propylitic appearance, of Rosenbusch, and may correspond in part to the dacites as well as to the porphyrites of Fouqué and Lévy that are likewise analogous to some of the propylites described by Zirkel from the Virginia Range. In the same region these rocks sometimes have a lighter color owing to the abundance of disseminated feldspar crystals which give a more marked porphyritic appearance. There may also be observed with the naked eye and in very variable quantity, grains of pyrite disseminated in the paste.

In the region of Guanacevi, Durango, altered andesites of green color form the rocks of the first eruption. With these are associated superposed andesitic tuffs and sometimes rhyolitic tuffs, likewise green, in beds of considerable thickness which

always contain veins of epidote visible in thin layers. The greater number of the mineral veins of this locality occur in these rocks. In the state of Sinaloa these greenstones abound in many of the mining districts, but are more or less altered by the contact of the metalliferous veins, now gold, now silver-bearing. These microlitic greenstones pass sometimes to an ophitic structure, and even to holocrystalline rocks of clearly granitic structure giving types of diorites and diabases. In the territory of Tepic green andesites occur in great quantity, always with analogous characters. In the state of Jalisco green dacites occur at the mines of Los Reyes, San Sebastian, and Real Alto.

In Fresnillo and Sombrerete, in the state of Zacatecas, rocks of similar aspect are found covered by an extensive formation of rhyolite tuffs.[1] In the district of La Luz, state of Guanajuato, the small size of the mineral elements and the profound alteration which the rocks have undergone prevents usually an exact microscopic determination of the minerals or the rock structures. It is, however, possible in some cases to observe characters which show that the rocks approximate to andesitic porphyrites or hornblende andesites.[2] It is interesting to note that there exist great similarities between the rocks of La Luz and those associated with the rhyolite tuffs in the mines of the state of Zacatecas. The fine grain of the former rock has indeed caused it to be called a rhyolite tuff.

As regards the age of the formations of La Luz and those about the city of Guanajuato, various conclusions have been reached, owing to the absence of fossil remains in the sediments, as well as the complex nature of the eruptive regions of the vicinity. The rocks of the latter regions, which include the hornblende granites of Santa Ana and the granites of the Ser-

[1] The rocks classified as rhyolite tuffs are some of them andesitic tuffs which appeared during the eruptions of andesites, and were later impregnated with silica, while others were derived from the eruptions of rhyolites.

[2] The term porphyrite is restricted in use by Ordoñez, but is employed by him to designate Tertiary rocks differing slightly in appearance from the common andesites and showing peculiar alteration.

rania del Gigante, belong undoubtedly to a pre-Cretaceous epoch. Fragments of these granites, syenites, etc., occur in the red conglomerate of Guanajuato. They are undoubtedly anterior to the rocks of La Luz, which may be considered to be recent Tertiary.

In the metalliferous regions of Pachuca, Real del Monte, and El Chico, in the state of Hidalgo, altered pyroxene-andesites and dacites of green, dark and light gray, and violet color, constitute the predominating eruptive rocks. They are distinguished from the rocks previously cited chiefly by their structure, which may be considered as invariably trachyto-porphyritic; a structure produced by large crystals of labradorite and altered remains of crystals of pyroxene. Andesite tuffs like those of Guanacevi or rhyolite tuffs like those of Zacatecas scarcely occur at all. There are many other points along the Sierra Madre where the andesitic greenstones occur, chiefly in the states of Chihuahua, Sinaloa, Durango, Jalisco, and the territory of Tepic. From these the regions of Zacatecas, Guanajuato, and Pachuca are somewhat distinct from an orographic point of view. Considered petrographically, however, they are mountain regions which, on account of the order of eruption of their igneous rocks, may be regarded as branches of the Sierra Madre penetrating toward the interior.

Trachytes and trachyte-andesites have in some of the localities mentioned immediately succeeded the andesites, either as a modification of the latter or as a later eruption. Trachytes are, however, relatively rare in Mexico, especially among the earlier eruptives. They are more frequent before the second period of andesites and in the modern eruptions.

The rhyolites appeared after the andesites, presenting the variations common to rocks of this type. They occur in many localities, only the principal ones of which can be indicated. In the central part of the Sierra Madre the rhyolites cover great areas. Here the structure passes from the micro-granulitic to one entirely vitreous giving obsidians and retinites. The rhyolites are likewise notably abundant in many places of the Mesa Cen-

tral, where some of them may be considered of later age than those of the Sierra Madre.

In general it can be said that the forms of the mountains of rhyolites are always characteristic, serving in many cases to foretell their nature, especially when this rock occurs alone in an extensive portion of one serrania. Of those with sharp and elongated peaks we have a good example in the peak of Bernal in the state of Queretaro. The extended forms present us great cliffs (*acantilados*) in the extensive serrania of Valdecanas and in the no less interesting Sierra Fria in the state of Zacatecas.

In the second of these serranias, formed in great part of rhyolites, variations of structure and texture have brought about the formation of plateaus and dome-like summits and erosion has given rise to broken, fantastic shapes. In this sierra as in many other localities formed of the same rock, the spherulitic rhyolites of slightly coherent or tufaceous paste alternate in beds more or less horizontal or parallel with petrosiliceous rhyolites charged with quartz, which are compact and resist the forces of erosion. The result is an appearance of steps or stairs at different heights on the slopes of the mountains. The surfaces of the separated blocks, as a result of contraction or atmospheric action, generally have columnar or other imitative forms, such as are shown by some of the peaks called The Friars; a name by which rocks of columnar structure are designated in various parts of the country.

As notably spherulitic rhyolites can be mentioned those of Chichindaro, in the state of Guanajuato, and those of San Ildefonso, Tula, Hidalgo. There are spherulitic and perlitic retinites in Apaseo el Alto, which are of pretty appearance on account of the contrast of color which the gray or black amorphous paste offers to the generally red spherulitic globules. But the most abundant rhyolites are the petro-siliceous rhyolites of various shades, red, black, violet, etc., such as those of the Sierra del Jaral and other points in the vicinity of the regions of San Luis Potosi, together with those of Guanajuato, Pozos, Peñoles, etc. Some of the latter frequently are accompanied

by retinites, which may come to predominate, as in the hill Xicuco between Tula and Mixquiahuala of the state of Hidalgo. The violet-colored rhyolites that occur in flows in the Tertiary formations of the Acacico near Yahualica, Jalisco, are notable for the curious forms (axiolites) which the microfelsitic paste presents under the microscope; forms very similar to those which Zirkel describes in a rock from the Black Rock Mountains, Nevada.

In the central part of the country between the parallels 19° and 21′ N. Lat., a notable eruptive zone exists. In this zone the appearance of modern eruptives has commenced generally with the rhyolites, to which have succeeded andesites of a second eruption, a lesser number of trachytes and the labradorites and basalts which form the chief eruptions of the modern volcanoes.

The andesites of the second epoch always present characters by which they can readily be distinguished from those of the first. The orthorhombic pyroxene, hypersthene occurs frequently among the ferro-magnesian elements of the rocks, now as a principal and now as an accessory constituent. The microlitic feature so marked in the earlier rocks diminishes little by little and the proportion of the amorphous groundmass, always devitrified, is increased.

A grouping of the andesites by regions, subdividing them by varieties of structure or the predominating ferro-megnsian element, is not practicable on account of the constant change which occurs in the nature of the component minerals and degree of crystallization. The hornblende-andesites of a microlitic and felsitic magma sometimes containing quartz (dacites) appear to have been erupted immediately after the rhyolites in the second andesitic period. The dacites are anterior to the pyroxene-andesites, likewise of the second epoch, as is shown by the frequently observed superposition of the latter and by the thick sedimentary deposits which have covered the dacites. Alluvium with pebbles of dacite is also found at great depths in the interior of several of the valleys. The hornblende-andesites

are distinguished as a general rule from the hornblende-andesites of theformer epoch by the exclusive existence of gray hornblende with strong dichroism, altered often in the periphery of the crystals into ferruginous products. The colors which generally predominate are grayish-violet and red. The latter color comes from the alteration of the violet by the decomposition of the crystals of amphibole into oxides of iron which are disseminated in the groundmass. The majority are of trachyto-porphyritic aspect.

Contemporaneous with or perhaps previous to these andesites should be noted the greater part of the hornblendic or micaceous trachytes whose number is, to be sure, limited, especially if compared with the number of those which were considered trachytes before the application of the microscope. The presence of hypersthene in abundance in andesites marks the end of the andesitic eruption, since such andesites are seen alternating with the basalts of modern outflows.

Hornblende-hypersthene-andesites are found in abundance in many places. Such are localities in the sierra which bounds the valley of Mexico on the west, in the valley of Toluca and in some parts of the Sierra Madre of the state of Chihuahua. The vitreous types of these rocks and some dacites frequently occur. These present a vitreous magma having spherulitic and perlitic structures. Andesitic obsidians with amphibole or mica are found in dikes as intrusives in the valley of Mexico.

Passing to the andesites made up wholly or chiefly of hypersthene, two varieties may be distinguished: first, those having a largely microlitic groundmass, and, second, those in which the amorphous groundmass predominates (andesitic obsidians). In many localities the two aspects of structure are associated and the fact that they grade into one another shows that the differences arise from variations in the conditions at the time of eruption.

In the andesitic-obsidians the augite appears successively in the first and second generations and then under a quasi-crystal line form, that is, as a simple devitrification of the amorphous

groundmass, or even in very small microlites. The andesitic eruptions of our volcanoes have produced these vitreous rocks charged with pyroxene. Such may be seen in the lavas of the volcano Colima and the early eruptions of Popocatepetl.

While andesites of the vitreous types predominate in the more recent eruptions, trachytes of the vitreous type also occur. The lavas of 1870 thrown from the volcano of Ceboruco furnish us a good example of this and may be designated as obsidian-like pyroxene-trachytes. Vitreous trachytes are likewise found in the volcanoes of Popocatepetl and Colima.

The presence of olivine as an accidental element in these rocks gives them to the naked eye the appearance of basalts. With these they have sometimes been confounded owing to the similarity of color and superficially blistered appearance, common to the basaltic lavas. There can be no doubt that they pass from one to another by insensible gradations since the diminution of oligoclase with the absolute predominance of labradorite, brings them to basic types represented by labradorites and basalts. Such gradations may be actually observed in some places in the valley of Mexico.

After the hornblende-andesites, which seem to have succeeded the rhyolites, the eruptions continued not only by emission of compact rocks, but also by an enormous quantity of broken products that were changed to sediments by watery vapors of the same eruptions and by atmospheric agencies Thus have originated those thick deposits of andesitic tuffs, breccias, etc., which are so abundant in different portions of the great central valleys of the country. The more superficial layers, having the lightness and fineness of detritus, have indeed been confounded at times with æolian products.

Lastly may be noted the labradorites, that is, basalts containing no, or only accidental, olivine, and the true basalts which occur in the volcanic regions or in rare cases rest upon or break through the Cretaceous limestones.

Labradorites occur in contact with the andesites of the first epoch and rhyolites, at various points along the eastern slopes of

the Sierra Madre. Among these points may be mentioned El Parral, in the state of Chihuahua; El Nayarit, in the territory of Tepic; the eastern part of the state of Jalisco; and near the volcano of Jorullo in the state of Michoacan. The early age of these labradorites is indicated by the fact that olivine is rare or absent. In the modern labradorites it occurs with more frequency.

These labradorites frequently exhibit a columnar structure, the most striking example of which is seen in the famous columns, 130 feet in length, along the Barranca of Regla in the state of Hidalgo. These stand upon Tertiary tuffs, resting in their turn upon arenaceous Upper Cretaceous limestones. The labradorites are compact, of gray color, and contain scattered grains of olivine. Geodes of zeolites occur in the columns, chabazite being most common, while thomsonite and arragonite are also found. The later series of labradorites and basalts continued up to the latest volcanic eruptions. Examples are found in the mountains about the valley of Mexico, as in the Peñon de los Baños, where pyroxene-labradorites in thin layers exhibit curious undulations. In some lava flows near the volcano of Ajusco at the southern part of the valley occur labradorites formed simply by a marked diminution of the olivine in the basalts which predominate in the region.

The vitreous hypersthene-andesites which formed the larger part of the early volcanic outflows were succeeded by basalts erupted through new volcanic foci. These exhibit an abundance of olivine in a microlitic groundmass of labradorite and pyroxene. The outflow of basalts in turn ceased, however, and the field was left anew to the hypersthene rocks which characterize the lavas of the volcanoes now in activity. This alternation is illustrated by contrasting the olivine-basalts of Jorullo of the middle of the last century with the present outflows of Ceboruco and Colima which present good types of trachytes and pyroxene-andesites with vitreous groundmasses.

In the northern region of the country, over the Mesa Central and along various points of the eastern Cordillera Madre,

basalts occur cutting their way through Mesozoic sediments and covering the Tertiary eruptives. In the plain extending to the south of the Cordillera of Mazapil and in the portion between the mountains of Gruñidora and Ahorcados, Tertiary basalts come up through the schistose Cretaceous limestones and along the upper surface of the latter marked metamorphism has been produced by the contact.

After the work of eroding waters had filled the valley of Mexico and made it habitable by man, a mighty cataclysm devastated the southern part of the valley. A flow of basalt ten miles in length, accompanied by showers of ashes, came from the volcano of Xitli and buried much of the inhabited region. Hence in the layers of pumiceous tuffs upon which these lavas rest, numerous utensils of primitive industry, human bones and bones of other modern vertebrates are found. The volcano of Toluca had ceased activity at this time, but Popocatapetl continued to pour forth eruptions of hypersthene-andesites. The eruptions of the latter volcano ceased at the beginning of this century, and now only a solfataric activity exists. The same is true of the Pico de Orizaba.

About the middle of the last century a new volcano appeared in the Mal Pais in the state of Michoacan. Its products were black basalts highly charged with olivine. With this last volcanic phenomenon was closed the prolonged inundation of basaltic and andesitic lavas which began to make itself felt at the end of the Tertiary period.

OLIVER C. FARRINGTON.

THE STRATIGRAPHY OF THE POTOMAC GROUP IN MARYLAND.[1]

CONTENTS.

INTRODUCTION.

The recent controversy regarding the age of the Potomac formation, which has been precipitated as the result of the conflicting evidence presented by the palæobotanists and the vertebrate palæontologists, suggests the necessity of determining the

[1] The investigations have been carried on under the auspices of the Maryland Geological Survey and the Woman's College of Baltimore.

sequence of the Potomac deposits, together with the horizons from which the fossils have been derived, if the questions at issue are to be finally settled. The authors of this paper have been engaged upon the investigation of these relations during the past year, and believe that much of the difference of opinion is due to the lack of knowledge regarding the stratigraphic position of the beds which have yielded the various plant and animal remains. They desire at the outset, however, to express their obligations to their predecessors in the field, without the results of whose work their own investigations would have been seriously retarded, if not rendered entirely abortive. The great volume of data which the palæobotanists have presented to us during the past few years, and the more meager evidence of the vertebrate palæontologists, have been of signal service in interpreting the stratigraphy of the Potomac formation. It is a pleasure to witness to the splendid achievements of Professors Ward, Fontaine, and Newberry, in the study of the fossil floras, and of Professor Marsh in extricating from poorly fossiliferous beds the important vertebrate remains which he states he has in store for us. The junior author of this paper has also made collections of the flora and fauna which will be discussed by him in a subsequent contribution.

The conclusions reached by those who have studied these two classes of organic remains may be briefly stated as follows: The palæobotanists, largely upon the discovery of dicotyledonous types of plant life, claim the Cretaceous age of the Potomac group, while Professor Marsh upon the evidence of the vertebrate remains, particularly of the Dinosauria, is as firmly convinced of the Jurassic age of the deposits.

It seems to the authors that the difficulty lies in the fact that each side has assumed too largely the unity of the Potomac group and has not sufficiently regarded the possibility of its representing more than a single formation. A marked exception to this is found in the late work of Professor Ward who has discovered several distinct stages in the fossil floras—a discrimination which is of much importance in determining the

stratigraphic relations of the higher portions of the Potomac deposits.

It is the conclusion of the authors, founded upon a detailed stratigraphic study of the Potomac group, that all the beds which have afforded dicotyledonous types of plant life are above those which have yielded the vertebrate remains, and, moreover, that a marked unconformity exists between the two series of deposits. The evidence for this conclusion will be brought out in the succeeding pages.

DESCRIPTION OF THE DEPOSITS.

The several formations into which the larger unit of the Potomac group has been divided are as follows:

Lower Cretaceous - -	(Raritan Formation) (Patapsco ")	Potomac
Upper Jurassic (?) - -	(Arundel ") (Patuxent ")	Group

THE PATUXENT FORMATION.

Name and areal distribution.—The Patuxent formation receives its name from the Patuxent River in the basin of which deposits of this horizon are found typically developed. As the basal member of the Potomac group the Patuxent formation occupies a position near the landward margin of the Coastal Plain, although the higher members of the series frequently overlap it and are found resting upon the crystalline rocks of the Piedmont Plateau to the westward. The Patuxent formation has been traced as a narrow, broken belt from Cecil county across Harford, Baltimore, Anne Arundel, and Prince George's counties to the borders of the District of Columbia.

Leading features of the deposits.—The deposits of the Patuxent formation consist mainly of sand, at times quite pure and gritty, but generally containing a considerable amount of kaolinized feldspar, producing a clearly defined arkose. Clay balls are at times distributed in considerable numbers through the arenaceous beds, which in places contain lenses of gravel, sometimes

with cobble stones. Frequently the sands pass over into sandy clays and these in turn into more highly argillaceous materials which are commonly of light color, but at times become lead-colored, brown or red, and not unlike the variegated clays of the Patapsco formation. Those arenaceous materials which lie adjacent to ferruginous clays are not infrequently indurated by hydrous oxides of iron, forming ferruginous sandstone. The more arenaceous deposits are commonly cross-bedded, and the whole formation gives evidence of rapid deposition.

The strike of the beds is in a general north-northeast south-southwest direction, corresponding to the eastern border of the Piedmont Plateau. The dip of the strata, so far as can be determined from the narrow exposures which have been obtained, is probably between thirty and forty feet to the mile. The irregular character of the sedimentation, together with the small areal extent of the deposits, renders it very difficult to make any satisfactory measurement.

The thickness of the Patuxent formation is rather variable, but, so far as has been determined, has not been found to exceed 150 feet, although it may be considerably thicker at some points.

Characteristic local sections.—The deposits of the Patuxent formation outcrop, among other places, in the valley of the Little and Big Patuxent rivers, having been reached in the iron-ore openings which have been made at many points in the overlying Arundel formation. An excellent section is found in a cutting on the Baltimore and Ohio Railroad a short distance to the south of Contee. At the latter locality the coarse gravelly phase of the formation is well developed, and is unconformably overlain by the iron-ore clays of the Arundel formation. At the southern end of the cut the gravels have become cemented near the contact with the Arundel into a considerable ledge of conglomerate, by the leaching into them of the hydrous oxide of iron from the overlying deposits.

One of the most comprehensive sections of the Patuxent formation is at School House Hill, Baltimore county, about three-quarters of a mile northwest of Lansdowne on the Baltimore and

Ohio Railroad, where a gulch, known as "Deep Ditch," on the southern side of the hill, has opened up one of the finest sections of the Potomac group. The Patuxent, Arundel, and Patapsco

FIG. 1. View at School House Hill, Baltimore County, showing Patuxent sands overlain by Arundel clays.

formations are all exposed at this locality. The section is as follows:

SECTION AT SCHOOL HOUSE HILL, BALTIMORE COUNTY.

Patapsco.	Argillaceous sands more or less iron-stained, with variegated clays, and with ferruginous crusts; ash-colored, lignitic and somewhat indurated toward the base; silicified coniferous and cycacean trunks. - - - - -	10 ft.
Arundel.	Slightly indurated, ferruginous ledge containing abundant impressions of monocotyledonous plants. - - -	1 ft.
	Drab-colored clays, with beds of lignite, containing "brown" and "white ore," exhibiting impressions of ferns; dinosaurian teeth; ferruginous ledge at base. - - -	50 ft.

Patuxent.	Compact, yellowish, reddish, and variegated sands, locally carbonaceous; brown clays containing flakes of iron ore (hydrous oxide); lead-colored clays with fragmentary plant remains; ferruginous ledge containing pipe ore. - -	30 ft
	Compact jointed clays of great variety of color, red, lilac, and white predominating; "paint rock" and lenses of coarse gravel containing balls of clay and silicified coniferous wood, passing into - - - - - - -	20 ft
	Cross-bedded sand, slightly carbonaceous - - -	10 ft
	Total thickness, - - - - - -	121 ft

The slope of the hill is thickly covered with a wash composed of highly ferruginous sand charged with broken crusts of ironstone.

Another section of much interest is found near Federal Hill Baltimore city, where the Patuxent sands are apparently directly overlain by the Patapsco formation, lenses of the Arundel formation having been observed occurring in their proper stratigraphic position in the immediate vicinity. The section at Federal Hill, somewhat generalized, is as follows:

SECTION NEAR FEDERAL HILL, BALTIMORE CITY.

Raritan.	Sand and ferruginous sandstone containing silicified coniferous wood - - - - - - -	5 ft. 0 in
	Carbonaceous clays containing flakes of "white ore"	1 ft. 4 in
Patapsco.	Variegated clays with ironstone crusts - - -	34 ft. 6 in
	"Short" blue slickensides clay with logs of lignite and occasional fern impressions - - -	7 ft. 6 in.
	Fossiliferous "slaty clay," with ferns, cycads, conifers, monocotyledons and dicotyledons - - -	7 ft. 10 in.
	Indurated ferruginous layer containing "paint rock"	0 ft. 6 in.
Arundel.	Represented in immediate vicinity by lenses of lignitic clay with nodules of "white ore" and its derivatives - - - - - - - -	0 ft. 0 in
Patuxent.	White sand - - - - - - -	7 ft. 0 in.
	Coarse sand with clay-balls - - - - -	4 ft. 0 in.
	White clay - - - - - - -	5 ft. 0 in.
	Indurated gravel - - - - - - - -	4 ft. 0 in.
	Total thickness - - - - -	76 ft. 8 in.

Many other occurrences of the Patuxent formation might be cited both to the north and south of Baltimore, but enough have already been given to show its character and relations.

Fossils.—Very few traces of organic remains have as yet been found in the Patuxent formation. Those which have been obtained consist of lignetized coniferous wood, and various indeterminable vegetable fragments, among which no traces of dicotyledonous forms have been observed. A silicified coniferous trunk has been found *in situ* at School House Hill. One cycad trunk is also reported to have been seen in place in these beds. No animal remains have yet been with certainty detected.

THE ARUNDEL FORMATION.

Name and areal distribution.—The Arundel formation receives its name from Anne Arundel county where the deposits of this horizon are well developed. It has been traced as a broken belt all the way from Cecil county to the borders of the District of Columbia, and occurs as long narrow belts that extend in a general northwest-southeast direction forming a low angle with the border of the Piedmont Plateau.

Leading features of the deposits.—The deposits consist of a series of large and small lenses of iron ore-bearing clays which occupy ancient depressions in the surface of the Patuxent formation. These clays as most typically developed ("blue charcoal clays" of the miners) are drab colored, tough, and frequently highly carbonaceous, lignitized trunks of trees and limbs lying horizontally strongly compressed and frequently charged with or enclosed by carbonate and sulphide of iron. Sometimes these trunks are encountered in an upright position, with their larger roots still intact. Scattered through the dark clays are vast quantities of nodules of iron carbonate, at times reaching many tons in weight, and known to the miners as "white ore," "hone ore" or "steel ore." In the upper portions of the formation which have been exposed to atmospheric influences the carbonate ores have sometimes to considerable depth changed

to hydrous oxides of iron, which the miners recognize under the name of "brown" or "red" ore. Under these conditions also the originally drab-colored clays containing the carbonate

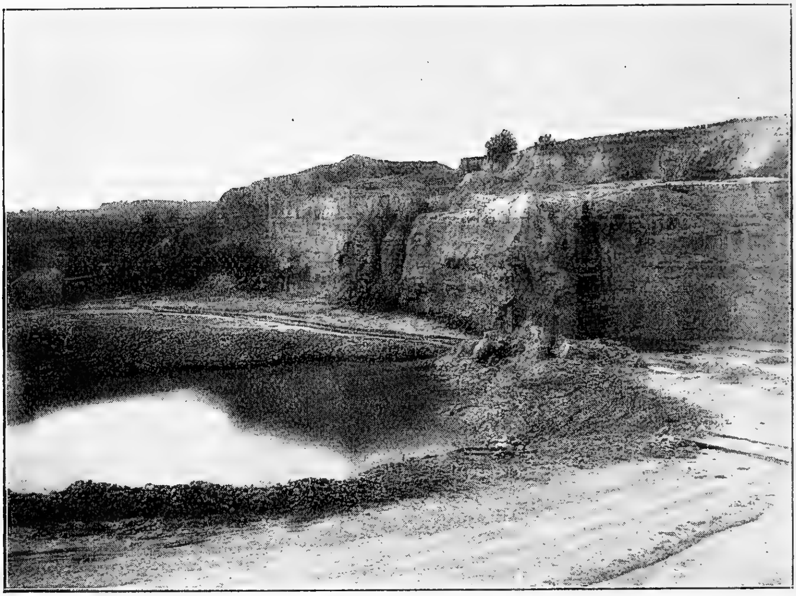

FIG. 2. Section at Reynold's Mine, Anne Arundel County, showing Arundel clays overlain by Patapsco formation.

ores have suffered a like chemical change, resulting in red or variegated clays. Where these clays chance to contain but little lignite the iron ore may consist almost entirely of these oxides.

The peculiar relations which the Arundel formation presents to the other members of the Potomac group render it difficult to say much regarding the strike and dip of the deposits, although the fact that they lie exposed in depressions upon the surface of the Patuxent formation renders it probable that these features do not differ materially from that observed in the other formations.

The lenses vary greatly in thickness, and from their character are at times lacking in portions of the country. The esti-

mates which were made of the thickness of the largest lenses observed render it probable that they attain at least 125 feet.

Characteristic local sections.— One of the best sections is found at Reynold's Mine on Piney Run, Anne Arundel county, one mile south of Hanover. It occurs on the western flank of the so-called "Elk Ridge" in a heavy lense constituting its axis and largely conditioning its existence. The section at Reynold's Mine is as follows:

SECTION AT REYNOLD'S MINE, ANNE ARUNDEL COUNTY.

Raritan.	White and light brown sand and gravel containing crusts of iron-stone - - - - - - -	10 ft. 0 in.
Patapsco.	White, varigated argillaceous sands, "fuller's earth," clay and paint clay, with paint rock at the base; silicified coniferous and cycadean trunks. -	10 ft. 0 in.
	Ferruginous ledge, more or less conglomeritic -	0 ft. 3 in.
Arundel.	Drab colored compact laminated clays containing beds of lignite and bearing fern impressions; nodules, flakes and ledges of "white ore," slightly plant bearing - - - - - - - -	70+ ft.
	Total thickness - - - - - -	90 ft. 3 in.

Another important section is found at Muirkirk, Prince George's county, where also the iron ore clays have been extensively worked for many years. The Muirkirk section exposed at the "Old Blue Bank" on the Tyson estate is as follows:

SECTION OF "OLD BLUE BANK" MUIRKIRK, PRINCE GEORGE'S COUNTY.

Raritan.	Sandy gravel - - - - - - - - - -	4 ft.
Patapsco.	Mottled gravelly loam; silicified coniferous and cycadean trunks - - - - - - - -	12 ft.
Arundel.	Massive blue clay containing "white ore;" bones of Dinusauria at base - - - - - - -	20 ft.
	Highly lignitic lens with "charcoal ore" - -	2 ft.
	Tough, "dry," blue clay with "white ore" - - -	15 ft
Patuxent.	White sand - - - - - - - - -	10+ ft.
	Total thickness - - - - - -	63 ft.

FIG. 3. Arundel formation showing nodules of "white ore" at Reynold's Mine, Anne Arundel County.

Many other characteristic local sections might be given, since the Arundel formation has been opened at numerous points for iron ore. Lenses have been observed among other places at the head of Elk River neck in Cecil county, in the vicinity of Joppa, Harford county, on Stemmers Run, Baltimore county, at Locust Point, Baltimore city, and at numerous localities in Anne Arundel and Prince George's counties.

Fossils.—Animal and plant remains have been observed at several localities in the Arundel formation. The Muirkirk area has afforded much the largest number. It was in this section that the vertebrate and cycadean remains of the Potomac group were first discovered by Mr. Philip T. Tyson. Later Professor O. C. Marsh of New Haven made extensive collections at this locality and upon this material based his conclusions regarding the age of the Potomac group. The vertebrate fossils consist largely of Dinosauria.

The plant fossils consist of ferns, conifers and monocotyledons. No dicotyledonous forms have yet been recognized.

THE PATAPSCO FORMATION.

Name and areal distribution.—The Patapsco formation is so called from its typical occurrence in the valley of the Patapsco River. It extends entirely across the state from the Delaware border to the Potomac River, and throughout this distance is one of the most important members of the Potomac group. It has a much larger areal extent than either of the two formations before described, and in places overlaps them, resting directly upon the crystalline rocks of the Piedmont Plateau.

Leading features of the deposits.—The deposits of the Patapsco formation consist chiefly of highly colored and variegated clays which grade over into lighter colored sands and clays, while sandy lenses of coarser materials are sometimes interstratified, which are occasionally indurated and at times form "pipe

ore." The clays are in places dark colored, massive and more or less lignitic. At times they are laminated ("slaty") and bear large numbers of leaf impressions. Fossiliferous flakes and nodules of "white" and "red ore" also occasionally occur. The sands sometimes contain much decomposed feldspar, and rounded lumps of clay are also found. The sands are frequently cross-bedded and give evidence of rapid deposition. Workable beds of "paint rock," as the highly ferruginous clays are termed, are found at many points, usually near the base of the formation.

The strike of the formation has a general north-northeast south-southwest direction, following the eastern margin of the Piedmont Plateau. The dip of the beds is somewhat less than that of the underlying formations, the deposits of the Patapsco formation transgressing the older strata, and as a result often come to lie directly upon the crystalline rocks to the westward.

A very marked unconformity is found between the deposits of the Patapsco and underlying formations. The thickness of the formation is estimated to reach fully 200 feet.

Characteristic local sections.—In addition to the several characteristic sections which have been already given, in which deposits of the Patapsco formation are found represented, the highly important locality of Cedar Hill in the area of Timber Neck in Anne Arundel county is also described. The section is on Licking Run one mile southwest of Hanover and is as follows:

SECTION AT CEDAR HILL, ANNE ARUNDEL COUNTY.

Raritan.	Reddish sands, somewhat gravelly, containing "pipe ore"	12 ft.
Patapsco.	White, red and brown sands, more or less argillaceous, containing clay pellets - - - - - - -	20 ft.
Arundel.	Drab colored pyritous clays with beds of lignite; pellets, nodules and flakes of carbonate of iron ("white ore")	100 ft.
	White clay (in bed of Licking Run) - - - -	5 ft.
	Total thickness - - - - - -	137 ft.

Another interesting section is found on the opposite side of Licking Run in Reynold's "Spring Drain" mine, where the basal member of the Patapsco formation consists of a ledge of

FIG. 4. View of Timber Neck, Anne Arundel County, showing Arundel, Patapsco, and Raritan formations.

ferruginous conglomerate and is found lying unconformably upon the Arundel iron ore clays below. Innumerable sections of the Patapsco deposits are found in other mines and along the streams, railroads, and highways which cross this region.

Fossils.—The fossils which have been found in the Patapsco formation consist chiefly of plant remains. A few poorly preserved molluscan shells have been observed but no study has yet been given to them. No dinosaurian remains have yet been with certainty detected.

The plant remains consist mainly of ferns, cycads, conifers, monocotyledons and dicotyledons. The dicotyledonous forms are not uncommon and according to Professor Lester F. Ward

who has made a very exhaustive study of the flora from this horizon, represent among their number a few archaic types, while others approach quite closely to modern types of vegetation.

THE RARITAN FORMATION.

Name and areal distribution.—The Raritan formation receives its name from the Raritan Bay, New Jersey, where the deposits of this formation are typically developed. The name was given by the senior author of this paper in the annual report of the state geologist of New Jersey for 1892 although the term Raritan clays had been somewhat loosely used for deposits of this age by earlier writers.

The Raritan formation extends as a constantly narrowing belt from northern New Jersey into Maryland and disappears by the transgression of the upper Creteaceous formations near the borders of the District of Columbia.

Leading features of the deposits.—The deposits of the Raritan formation consist of sands and clays, the former largely predominating in the upper portion of the formation. The sands are frequently very pure and white but at times, especially in the lower portion of the formation are more or less colored and indurated by hydrous oxide of iron which produces the characteristic tube-like structure which is known as "pipe ore.' The indurated beds are well exhibited at Rocky and Stony creeks on the south side of the Patapsco River, and at White Rocks in the immediate vicinity. The latter locality afforded the name of "Albirupean" which was applied by Professor Uhler to the upper portions of the Potomac group.

The clays are generally of very light color but at times become dark colored in the leaf-bearing zones. Beds of brown, black or earthy lignite, containing much pyrites, and occasionally amber (Cape Sable, Magothy River), have been observed at a few points. The clays are generally more or less arenaceous and grade over into the sandy deposits which largely characterize this formation.

The strike of the beds is in a generally north-northeast to south-southwest direction, corresponding to the Patapsco formation already described. The dip of the strata is probably

FIG. 5. Section of Raritan formation near Rocky Point above Round Bay, Severn River, Anne Arundel County, showing hard sandstone ledges at the right and white cross-bedded sands in the center.

slightly less than that of the underlying formation, and a slight transgression is noticeable to the northward.

The thickness of the Raritan formation in central Maryland is probably not far from 500 feet. It declines in thickness gradually to the southward where it finally disappears near the limits of the District of Columbia.

Characteristic local sections.—Very characteristic sections of the Raritan formation are shown in the bluffs of the Severn River in the vicinity and about Round Bay. On Rocky Point just above Round Bay an excellent exposure of the Raritan sands with the interbedded clays is exhibited, with a capping

of marine Cretaceous. The section at this point is as follows:

ROCKY POINT, ROUND BAY, SEVERN RIVER.

Matawan.	Black laminated sands highly weathered, producing a reddish and grayish motted appearance	10 ft.
Raritan.	Coarse, gritty sands with lenses of clay; the sand cross-bedded and often indurated, forming heavy ledges of ironstone	30 ft.
	Total thickness	40 ft.

Other excellent sections are seen on the Magothy River, on the Lower Patapsco and its tributaries, on Elk Neck, and near the mouth of the Sassafras River, in which very much the same characters are exhibited. The light colored sands are especially well developed on Elk Neck where they attain a very great thickness.

Fossils.—The fossils of the Raritan formation consist mainly of plant remains. Several brackish water molluscan shells have been obtained from the Raritan formation, farther to the north in New Jersey and it is not improbable that the same may be observed in Maryland when the deposits have been further studied. The fossil plants include dicotyledons of much more recent affinities than those of the Patapsco formation, the break between the two floras being very marked.

INTERPRETATION OF THE DEPOSITS.

The interpretation of the Potomac group involves the consideration of the sedimentation and structural relations of the deposits as well as of the entombed fossils, and each has an important bearing in the elucidation of the other. The conditions of sedimentation explain in no small degree the character of the fauna and flora while their features likewise throw light upon the physical conditions which existed during Potomac time.

Sedimentation and structural relations.—The sedimentation of this period can best be understood after an examination of

the physical conditions which prevailed during the time immediately preceding the opening of Potomac deposition. The results of recent work in the study of the physiography of the North

FIG. 6. Section below Round Bay, Anne Arundel County, showing Raritan formation overlain by Matawan formation.

American continent during the Mesozoic show that the eastern side of the country had been largely base-leveled, so that a long period of rock disintegration preceded the Potomac. With the advent of this period the land was tilted southeastward, and the increasing erosion brought about by this movement afforded the deposits of the Potomac group. That this movement was not continuous or persistent in the same direction is evidenced by the varying character of the deposits which have been already described. With the close of Potomac sedimentation a gradual transgression of the later marine formations across the margin

of the Potomac group took place, by means of which the higher strata were gradually cut off to the southward. The details of this transgression will be further explained in the subsequent pages.

The basal deposits of the Potomac group, which have been described under the name of the Patuxent formation, indicate in their arkosic character, their proximity to the ancient continent, the rocks of which had suffered extensive disintegration. These features so pronounced where the deposits lie adjoining gneissic or granitic rocks largely disappear where these rocks are poorly developed and where the deposits themselves were evidently laid down at some distance from the old shore line. Rapid deposition in shallow waters is seen in the cross-bedded character of the strata and their rapid change in character The appearance of clay balls, so widely disseminated at certain points, as above described, indicates the shallowing of the seas and the breaking down of pre-existing clay beds by wave action and the incorporation of the rolled materials by the later deposits.

The close of the Patuxent epoch was evidently marked by a gradual elevation of the deposits and the trenching of the surface by streams, so that a series of broad, shallow valleys was formed While this was going forward, a landward depression of the continent border evidently took place, producing series of long marshes in the ancient valleys, in which sedimentation was slow and in which swamp vegetation flourished. The tough clays, filled with lignitic accumulation, in which the tree trunks are sometimes found erect, with their roots still intact, can hardly find a satisfactory explanation upon any other basis. It was in these ancient marshes that the iron was deposited. It is also probable that some connection existed between these marshes and the area of basic eruptive rocks of central and northern Maryland. It was in these marshes that the bones of Dinosauria became entombed which, with the evidences of dense vegetation, suggests a sub-tropical climate.

The marked line of unconformity separating the Patapsco

formation from the two basal members of the Potomac group points to elevation after the close of the Arundel epoch and to a prolonged period of denudation. A striking feature of this erosion is the greater resistance which the Arundel clays presented when compared with the deposits of the Patuxent formation. The partially eroded clay lenses which project above the common line of contact can readily be explained upon these grounds. It was over this uneven surface that the deposits of the Patapsco formation were spread, reaching far beyond their western limits until they rested directly upon the crystalline rocks of the Piedmont Plateau. Their materials, so largely arkosic in the vicinity of the feldspathic rocks (gneiss and granite), point to the rapid stripping off of the disintegrated surface materials, and their deposition along the continent border. To how large an extent subsequent disintegration has kaolinized these materials it is difficult to determine, but that they had been extensively weathered prior to their removal seems justified. The highly colored and variegated clays which were evidently formed in the quieter and deeper waters of the Patapsco epoch bear some relation to the great belts of basic eruptive rocks which lie to the west and north of them. This phase of sedimentation is much more marked in central Maryland where the rocks of this character are most highly developed and where the proximity to the eastern margin of the Piedmont belt is most apparent. It is also probable that these highly colored clays were in part derived from the weathered surface of the Arundel iron-ore beds.

The unconformity separating the Raritan from the underlying deposits is less prominent than that which has been above described at the base of the Patapsco formation, although the gradual thinning of the Patapsco along its western margin and the overlapping of the Raritan points strongly toward a structural break. The Raritan deposits also obliquely transgress the other materials of the Potomac group northward until in the Delaware valley they come to rest directly upon the crystalline rocks of the Piedmont belt. The thick deposits of sand and

clay indicate rapid deposition in shallow waters and the general continuity of the beds points to wider and deeper water areas. The close of Raritan sedimentation by the depression of the continent border and the gradual transgression of the deposits of the marine Cretaceous southward is a phenomenon of unusual interest.

The line of unconformity which separates the Potomac group from the later Cretaceous formations is so poorly defined in local sections that absolute unconformity could hardly be proved except by the evidence of this gradual southward transgression which finally cuts off the entire Raritan formation on the banks of the Potomac River.

This review of the conditions of sedimentation during the Potomac period and of the relations which the individual formations hold to one another and to the rocks above and below them points to the probability of the existence of extended areas of fresh and brackish waters along the eastern border of the North American continent during Potomac time. Just how these conditions could have been produced in all instances is not clear and speculation regarding them seems hardly warranted by the facts which are at present before us.

Correlation.— The correlation of the formations composing the Potomac group must rest largely upon the fossils which have been derived from them, although the physical history of the continent renders it possible to establish certain broad comparisons along the Atlantic and Gulf borders that are not without their value. The similarity of conditions during the deposition of the Tuscaloosa beds in the south is clearly indicated, and the corroborative evidence which palæontology affords in this connection will be presently mentioned.

As was stated in the introduction to this article the tendency of most authors hitherto has been to regard the Potomac group as a single stratigraphic unit and the discovery of fossils of known affinities within its beds to be conclusive evidence of the age of the entire series of strata. From what has been said in the preceding chapters it is evident that the Potomac group is made

up of a series of formations, containing clearly defined faunas and floras, and separated by marked structural breaks at various points. It is necessary, therefore, to correlate each division of the group upon its own merits, and not upon the floral or faunal relations of the underlying and overlying formations.

The absence of knowledge regarding the character of the organic remains entombed in the Patuxent formation renders it impossible to speak with definiteness regarding the age of this division. Its position beneath the Arundel beds and the physical relations which it holds to this formation render it probable that they must both be assigned to approximately the same position in the geological time scale. The Arundel formation has afforded a number of vertebrate forms, largely Dinosauria, which Professor Marsh regards as indisputable proof of the Jurassic age of the deposits. The fossil plants which have been hitherto found in this formation are altogether in harmony with this view. No dicotyledonous types have been observed, while the ferns, conifers and monocotyledons could, so far as at present known, be as well referred to the Jurassic as to a later horizon. The evidence afforded by the vertebrate fossils is unfortunately incomplete as but few forms have as yet been figured and described, although Professor Marsh states that he possesses a large amount of unpublished material which fully corroborates the views which he has promulgated regarding the age of these beds. Professor Marsh admits the equivalence of these beds with portions at least of the Wealden formation of Europe which most authorities refer to the Cretaceous. The final interpretation of the vertebrate fauna evidently involves, therefore, the determination of the upper limits of the Jurassic itself rather than the correlation of the Potomac group simply, and this article is hardly the place to discuss the merits of so broad a question. It is not impossible, however, that portions of the Potomac as well as the Wealden may antedate the oldest known marine Cretaceous, and for that reason as well as on account of the distinguished authority of Professor Marsh the Patuxent and Arundel formations are provisionally referred by the authors to the Jurassic. The discov-

ery of vertebrate remains of Jurassic affinities in these formations is not, however, sufficient grounds for the reference of the entire Potomac group to the Jurassic period.

The Patapsco formation has afforded a rich flora in which dicotyledonous types are not uncommon. The fact that dicotyledonous forms have never been found elsewhere in rocks earlier than the Cretaceous is strong presumptive evidence of the Cretaceous age of these deposits; at the same time the fact that many other forms are identical or closely related to those of European horizons, generally referred to the Cretaceous, further substantiates this view. It is the opinion of Professor Ward, who has exhaustively studied the flora of this formation, that it is equivalent to the lower divisions of the Lower Cretaceous of Europe. Professor Ward has divided what the authors here recognize as a single stratigraphic unit into several zones, each with its characteristic plant forms, which, he states, give evidence of constantly progressive types in passing from the lowest to the highest members of the series. Whether these different zones represent a sequence of floras, or to a considerable extent local aggregations of forms under different physical conditions but of equivalent age, the authors are unable to determine, although they strongly incline to the latter view. The abundance of vegetation having a prominent cycadean element suggests a repetition of the mild climatic conditions which prevailed during the Arundel deposition.

The fossils of the Raritan formation are in the main distinct from those of the Patapsco and include a large assemblage of dicotyledonous types with much more modern affinities. Similar forms are found in the Tuscaloosa beds of the south, and it is the belief of Professor Ward that these deposits represent the Raritan formation in the north. The Raritan beds show strong floral affinities with the upper portions of the lower Cretaceous of Europe (Albian), and, according to Professor Ward, it is not impossible that the higher members of this formation to the north of New Jersey may even represent the basal portions of the upper Cretaceous as well (Cenomanian).

The Patapsco and Raritan formations have afforded no animal remains which are of determinative value; the fossil plants all point strongly to the lower Cretaceous age of the beds. So large an amount of evidence has been brought forward in support of this view by Professors Ward, Fontaine and Newberry, that the authors have no hesitancy in accepting their conclusions, and these two formations are therefore placed in the Cretaceous.

THE TAXONOMIC VIEWS OF OTHER WRITERS.

The earlier writers did not differentiate the Mesozoic deposits of the middle Atlantic slope into independent formations. For many years the basal clays and sands, which border the crystalline rocks of the Piedmont Plateau on the east, were considered the eastern equivalent of the red sandstones and shales with their enclosed coals farther west.

Professor W. B. Rogers, state geologist of Virginia, first sharply differentiated the eastern deposits from the western, and described the former under the name of the "Upper Secondary"[1] in his state report. In later articles Professor Rogers refers these deposits "at least in part to the horizon of the Upper Jurassic. Possibly we may find here a passage group analogous to the Wealden of British Geology."[2] On his geological map of the Virginias, and in his more recent publications, the deposits of the Potomac group are referred to as the "Jurasso-Cretaceous."

In the reports of Professor J. T. Ducatel, who was state geologist of Maryland between the years 1834 and 1841, comparatively little attention was given to the clays and sands at the base of the Coastal Plain series, and neither their stratigraphic nor taxonomic position was clearly defined. The reëstablishment of official geological work in Maryland by Philip T. Tyson,[3] who, as state agricultural chemist, published

[1] Geology of the Virginias. Report of 1840, p. 438.

[2] Geology of the Virginias, p. 712.

[3] First Rept. State. Agri. Chem., 1860, pp. 41–43.

his first report in 1860, led to a much fuller description of the Potomac deposits. He recognized two divisions in these basal strata, although his descriptions do not make it altogether clear that he understood their stratigraphic relations. He, however, differentiated the "Iron-ore Clays" which he described and mapped as distinct from another member composed of variegated materials ("a thick group of sands and clays of various colors"). He stated that this latter member in places abounded in lignite derived from coniferous plants, and in places contained beds of ferruginous sandstone. These deposits were referred with the sandy clays and greensand above them to the Cretaceous or Upper Secondary. In his second report, published in 1862, he referred the "Iron-ore Clays," on the supposed occurrence of fossil cycads in the beds, to the "Oolitic period."

In the "Memoir of the Geological Survey of Delaware,"[1] published by Professor J. C. Booth, the state geologist of Delaware, in 1841, the deposits which we are now considering were denominated the "Red Clay formation," and together with the "Greensand formation" above them classed as "Upper Secondary Deposits."

Professor H. D. Rogers, who published reports upon the geology of New Jersey in 1836 and 1840, described the deposits of that region as "Clays and Sands" without clearly defining their stratigraphic relations. Upon the organization of the second Geological Survey of New Jersey in 1854 under the direction of Wm. Kitchell, Professor George H. Cook began his extended investigations of the Coastal Plain series of that state. At a later period, as state geologist, he elaborated and classified these deposits in a manner that for many years met with wide acceptance. This classification is given in much detail in the *Geology of New Jersey* published in 1868.[2] The lowest of these formations is described by Professor Cook under the name of "Plastic Clays" and referred by him to the Cretaceous.

Little further attempt was made at the investigation of the

[1] Mem. Geol. Surv. Del., pp. 38–43.

[2] Geology of New Jersey 1868, pp. 249–257.

Potomac deposits until almost within the last decade. In 1885 Professor R. P. Whitfield, as the result of several years' study, published an important monograph upon "The Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey," in which several Lamellibranchs from the "Plastic Clays" of Professor Cook are described. While the investigations leading up to Professor Whitfield's report were in progress Professor William M. Fontaine, of the University of Virginia, began his elaborate study of the Mesozoic flora of Virginia. The published account of this work, however, did not appear until after the important stratigraphic study of Professor W J McGee, of the United States Geological Survey, which began a few years subsequently.

The investigations of Professor McGee upon the Potomac deposits were seriously commenced in the summer of 1885, and were participated in by Professor L. F. Ward, of the United States Geological Survey, and these gentlemen also coöperated soon after with Professor Fontaine. Some preliminary work had already been done by Professor McGee[1] in the previous year and the name "Potomac formation" proposed. Professor McGee continued his investigations of the Potomac formation during several years, and published a number of important papers regarding its stratigraphic features, the most comprehensive of these being entitled "Three Formations of the Middle Atlantic Slope."[2]

During this same period Professor P. R. Uhler,[3] of Baltimore, investigated the relations of the Potomac deposits in the Patapsco basin of central Maryland and proposed the division of these basal deposits into a lower member which he called the "Baltimorean," and an upper member which was designated the "Albirupean." In later publications[4] the term Potomac was accepted as the equivalent of the Baltimorean, and the "Alter-

[1] Rept. Health Officer, Dist. Columbia 1884–5 (1886), p. 20.

[2] Amer. Jour. Sci., 3d ser. Vol. XXXV, 1888, pp. 120–143.

[3] Proc. Amer. Phil. Soc., Vol. XXV, 1888, pp. 42–53.

[4] Md. Acad. Sci., Vol. I, 1892, pp. 185–202.

nate Clay Sands" placed at the top of the group as part of the Albirupean.

The senior author of this paper, in a study of the Coastal Plain formations of New Jersey, proposed in 1892 the name "Raritan formation"[1] for the "Plastic Clays" of Professor Cook, the term Raritan having been somewhat loosely used by several authors in earlier years in speaking of the clay deposits of this formation.

Mr. N. H. Darton,[2] of the United States Geological Survey, as a result of his study of the Coastal Plain in southern Maryland, differentiated a part of the sands at the top of the Potomac group as the "Magothy formation," which he considered might be equivalent to Professor Uhler's "Alternate Clay Sands."

The elaborate investigations of Professor Ward, which began as already described in 1885, have been continued to the present day. His exhaustive researches upon the fossil plants in the Potomac group have added largely to our knowledge of that formation. His most important publication[3] appeared in 1895, in which the Potomac formation is subdivided into a number of series, viz.:—

Albirupean Series,	Newer Potomac.
Iron Ore "	Older Potomac.
Aquia Creek "	
Mt. Vernon "	
Rappahannock Series,	
James River "	

The interest aroused in the age of the Potomac formation led to the collection by Mr. J. B. Hatcher under the direction of Professor O. C. Marsh[4] of the United States Geological Survey of vertebrate remains from the iron ore beds in the vicinity of Muirkirk, Prince George's county, Maryland. Upon the basis of these remains Professor Marsh has unequivocally referred the Potomac group of Maryland to the Jurassic. He has sub-

[1] Ann. Rept. State Geol., N. J., 1892 (1893), pp. 181–186.

[2] Amer. Jour. Sci., 3d ser., Vol. XLV, 1893, pp. 407–419.

[3] 15th Ann. Rept. Dir. U. S. Geol. Survey 1893–4 (1895), pp. 307–397.

[4] Amer. Jour. Sci., 3d ser., Vol. XXXI, 1888, pp. 89–97.

COMPARATIVE TAONGMIC TABLE.

		W. B. Rogers (state report)	W. B. Rogeers (later)	J. C. Booth	P. T. Tyson	G. H. Cook	R. P. Whitfield	J. S. Newberry	W. J. McGee	W. M. Fontaine	P. R. Uhler	N. H. Darton	O. C. Marsh	L. F. Ward
CRETACEOUS	Raritan	?	?		?	Plastic clays	Raritan clays	Amboy clays	?	?	Alternate clay sands	Magothy		Albirupean series
	Patapsco	Upper Secondary	Jurasso-Cretaceous	Red clay Formation (upper secondary)	Variegated clays and sands				Potomac	Potomac or Younger Mesozoic	Albirupean Potomac or Baltimorean	Potomac	Potomac (Jurassic)	Iron ore series Aquia Creek series Mt. Vernon series Rappahannock series James River series ?
JURASSIC ?	Arundel													
	Patuxent	?		?	Iron ore clays									
					?									

sequently placed all of the Coastal Plain deposits beneath the marine Cretaceous in the same geologic division.[1] Professor Marsh claims the more recent discovery of a large amount of vertebrate material which throws much light upon the age of the Potomac formation and which he proposes shortly to describe. The last contribution of Professor Marsh brought about an extended discussion regarding the age of the Potomac group which was participated in by Messrs. Gilbert,[2] Marcou,[3] Hollick, Hill,[4] and Ward.[5]

The important postumous work of Professor J. S. Newberry entitled "The Flora of the Amboy Clays"[6] is a valuable contribution to the geology of the New Jersey portion of the Raritan formation. This work, which was edited by Arthur Hollick, represents the results of many years of investigation on the part of the late Professor Newberry.

The conclusions of the authors of this paper, as set forth in the preceding pages, are formed upon an extensive study of the Potomac group both in Maryland and New Jersey, and are seen to be quite different from those advanced by their predecessors. The comparative table on page 505 exhibits in a graphic manner the taxonomy of the several writers referred to, as interpreted by the authors of this paper.

WM. BULLOCK CLARK,
ARTHUR BIBBINS.

GEOLOGICAL LABORATORY,
JOHNS HOPKINS UNIVERSITY,
July 1897.

[1] Jurassic Formation of the Atlantic Coast, Amer. Jour. Sci., 4th ser., Vol. II, 1896, pp. 433–447; Science, n. ser., Vol. IV, pp. 805–816.

[2] Science, n. ser., Vol. IV, 1896, pp. 875–877.

[3] *Ibid.*, pp. 945–947; Vol. V, n. ser., 1897, pp. 149–152.

[4] *Ibid.*, pp. 918–922.

[5] *Ibid*, 1897, pp. 411–423.

[6] Monographs U. S. Geol. Surv., Vol. XXVI, Washington, 1895.

STUDIES FOR STUDENTS.

COMPARATIVE STUDY OF PALÆONTOGENY AND PHYLOGENY.

CONTENTS.

INTRODUCTION.

PALÆONTOLOGY ought to be synonymous with phylogeny, and biology with ontogenetic study; but when most palæontologists are content to describe species from a few characteristics of adults, and to guess at their relationships and history, and when many zoölogists are satisfied with basing species on color or some other minor mark, while the life history of even most living forms is wholly unknown, the need of higher ideals is evident.

All modern classification is intended to be genetic and is based on comparison of a series of adults from successive ages of the earth, of which the present time is but an episode. Interesting and valuable investigations in phylogeny have been made in this way, but such genealogies cannot, as a matter of course, be more than approximate, for the geologic record itself is incomplete, and the life record still more fragmentary. We

have nowhere a uniform succession of rocks, and nowhere an unbroken genetic series. It has been shown how often the facies of the Pacific coast[1] region has changed, and how it now belonged to one faunal region, and now to another, each great change in faunal geography showing some physiographic revolution here or elsewhere. Thus the local series is broken and filled in from other regions, species being classed together because of resemblance, while their real relationship is unknown.

LAW OF ACCELERATION OF DEVELOPMENT.

Since the geologic record is so badly broken, and since modern faunas and floras are but the topmost branches of a tree whose stock is only partly known, naturalists were merely groping in the dark in their efforts to get a genetic classification. There was however a glimmer of light, although scarcely heeded. No one man seems to have been the discoverer of the law of acceleration of development, but like the idea of evolution, it was in the air, and disclosed itself in various ways to the prophetic vision of seekers after truth. J. F. Meckel,[2] a German naturalist, seems to have been the first to give scientific expression to the biogenetic law, in his formula, "Gleichung zwischen der Entwicklung des Embryo und der Thierreihe," *comparison of development of the embryo with the race of animals.* But Louis Agassiz, although not the discoverer, was undoubtedly the first to use the law as an aid in the systematic study of biology. While he regarded the various genera, not as ancestors and descendants, but as progressive steps in creation, still he saw the analogy between the stages of growth of the individual and these progressive steps. It was reserved for Alpheus Hyatt to formulate the law, and to strengthen theory with practical examples based on study of Cephalopoda.[3] In his later papers Professor

[1] JOUR. GEOL., Vol. III, May–June 1895, Mesozoic Changes in the Faunal Geography of California. J. P. SMITH.

[2] Syst. Vergl. Anat., I., Theil Halle, 1821.

[3] A. HYATT, Mem. Boston Soc. Nat. Hist., Vol. I, 1866–7, and Proc. Boston Soc. Nat. Hist., Vol. I, 1866, "Parallelisms of Individual and Order among the Tetrabranchiate Mollusks."

Hyatt has given a more exact and comprehensive definition of the law of acceleration or *tachygenesis:* "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited in successive descendants at earlier and earlier stages according to the law of acceleration, until they either become embryonic, or are crowded out of the organization, and replaced in the development by characteristics of later origin."[1] A still more definite statement by the same author is the following: "The sub-stages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion and of proximal ancestral characters in direct proportion to their removal in time and position from the protoconch or last embryonic stage."[2] Since Hyatt's first paper the law has been rediscovered and renamed by Haeckel,[3] "das biogenetische Grundgesetz" and by Würtenberger.[4] But these naturalists, instead of adding anything to Hyatt's definition, have failed to reach its clearness and simplicity. The only real addition that has been made is Cope's[5] idea of retardation, by which is explained the separation in the ontogeny of the descendant of characters that occurred simultaneously in the ancestor. Cope says: "The *acceleration* in the assumption of a character, progressing more rapidly than the same in another character, must soon produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of *inexact parallelism*. As all the more comprehensive groups present this relation to each other, we are compelled to believe that *acceleration* has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has no doubt followed

[1] A. HYATT, Smithsonian Contributions to Knowledge, No. 673, "Genesis of the Arietidæ," Preface, p. ix.

[2] Proc. Am. Phil. Soc., Vol. XXXII, No. 143, A. HYATT, "Phylogeny of an Acquired Characteristic," p. 405.

[3] "Morphologie der Organismen," Vol. II; and "Anthropogenie," 1874.

[4] Ausland, 1873, and "Studien über die Stammesgeschichte der Ammoniten," 1880.

[5] Origin of the Fittest.

a law the reverse of acceleration, which has been called *retardation.* By the increasing slowness of the growth of the individuals of a genus, and later and later assumption of the characters of the latter, they would be successively lost."[1]

By a proper application of the law of acceleration as defined by Hyatt, and modified by Cope, all the facts of biology may be explained; there is no such thing as "falsification of the record." But as yet the law has had no great effect in classification, for most palæontologists have not approached their work from the biologic side, and biologists have been equally neglectful of the results attained by palæontology. A distinguished zoölogist once said to the writer, on being shown an ontogenetic series of ammonites, and the conclusions reached, "It is all beautiful, but almost too good to be true." In palæontology it is especially true that a naturalist may be a specialist in the fauna of one age, and know little of that of another. Hence the animals of various periods have been classified according to varying standards, all artificial. The only cure for these discrepancies is study of ontogeny, and comparison of stages of growth of the individual with ancestral genera. This will also prevent the description of supposedly new genera and species based on immature specimens, as has so often been done. The writer remembers once collecting numerous *Ceratites* in the Karnic limestone of the California Trias, much to his astonishment, for they ought not to occur so high up. He afterwards found, however, that they were not adults, but adolescent ceratitic stages of *Arpadites;* a similar case was the finding in the same horizon a *Tirolites* above its proper range, but it turned out to be the young of a *Trachyceras* that persisted unusually long in the *Tirolites* stage. At that time there was nothing in the description of these genera or any of their species to guide one, and so their ontogeny had to be worked out independently. But there is nothing in the description of almost any fossil genera and species to prevent just such mistakes, and they are constantly being made.

By careful study of ontogeny in comparison with phylogeny

[1] Origin of the Fittest, p. 142.

the palæontologist can correlate correctly fossil beds where even all the genera and species are new; he can even prophesy concerning the occurrence of *unknown* genera in certain horizons when he finds their minute counterparts in youthful stages of later forms; in fact he could often furnish just as exact a description of the form as if he had the adult genus before him.

NOMENCLATURE OF STAGES OF GROWTH.

In order to correlate ontogenetic stages with the generic changes seen in the development of the race it is necessary to have an exact scientific nomenclature. The most satisfactory is that given by Professor Hyatt in "Phylogeny of an Acquired Characteristic."[1]

TABLE OF ONTOGENETIC STAGES.

Stages	Stages	Substages	Comparison with phylogeny	
Embryonic	(1) Embryonic	Protembryo	Phylembryonic	Epacme
		Mesembryo		
		Metembryo		
		Neoembryo		
		Typembryo		
		Phylembryo		
Larval	(2) Nepionic	Ananepionic		
		Metanepionic	Phylonepionic	
		Paranepionic		
Adolescent	(3) Neanic	Ananeanic		
		Metaneanic	Phyloneanic	
		Paraneanic		
Adult	(4) Ephebic	Anephebic		
		Metephebic	Phylephebic	Acme
		Parephebic		
Senile	(5) Gerontic	Anagerontic		
		Metagerontic	Phylogerontic	Paracme
		Paragerontic		

With the embryonic stage the palæontologist can do nothing, except the very last substage or phylembryo, when the *Mollusca*, *Brachiopoda* and other groups begin to secrete their shells; but all the later stages are easily accessible in well-preserved material.

[1] Proc. Am. Phil. Soc., Vol. XXXII, No. 143, pp. 391 and 397.

The best example of correlation of ontogenetic stages with phylogeny is the genealogy of *Medlicottia*, worked out by Karpinsky,[1] who has shown that the Carboniferous genus *Pronorites* goes through the following stages: latisellate protoconch, phylembryonic; with the second suture it reaches the *Anarcestes* stage, nepionic; about the end of the first revolution the *Ibergiceras* stage begins, paranepionic; second revolution shows the *Paraprolecanites* stage, neanic; on the third whorl begins the *Pronorites* stage, adult. Thus with regard to *Pronorites* the genus *Anarcestes* is phylonepionic, *Ibergiceras* is phyloparanepionic, *Paraprolecanites* is phyloneanic. In the same work Karpinsky has shown that *Medlicottia* is a direct descendant of *Pronorites* and in its development goes through all the stages of the ancestral genus and adds several more. The first revolution of *Medlicottia* could not be studied, but on the second revolution was seen the *Ibergiceras* stage, metanepionic; on the third whorl the *Paraprolecanites* stage, paranepionic; at the end of the third whorl the *Pronorites* stage, beginning of the neanic; on the fourth whorl the *Sicanites* stage, end of the neanic: on the the fifth whorl the *Promedlicottia* stage, anephebic; and lastly, at end of the fifth whorl, *Medlicottia*, adult in characteristics, though not yet in size.

PALÆONTOGENY.

Groups available.—Vertebrates are out of the question for this sort of work, being too highly accelerated in their development; the stages that might be useful in phylogeny are gone through before the animal is capable of being preserved as a fossil. In the *Cœlenterata* the relations between Cenozoic and Palæozoic forms are not understood, and the ontogeny of available forms does not show stages that are striking enough to tell much. In *Echinodermata* difficulty of preservation of fossil forms makes ontogenetic study almost impossible, and recent forms have been too little studied for any comparison of stages of growth with ancient genera to be possible.

[1] Mém. Acad. Impér. Sci., St. Pétersbourg, VII Ser., Tome XXXVII, No. 2. "Ammoneen der Artinsk-Stufe."

The available groups are the *Brachiopoda*, the *Mollusca*, and the *Crustacea*.

Brachiopoda.—The brachiopods have this decided advantage, that they can be hatched in marine laboratories, and the various stages studied from the egg up, as has been done by Brooks, Kovalevski, Lacaze-Duthiers, Morse and Shipley, with the genera *Cistella*, *Glottidia*, *Lacazella*, *Liothyrina*, and *Terebratulina*. But it was reserved for the palæontologists Beecher, J. M. Clarke, and Schuchert to correlate the ontogeny of living forms with ancestral genera and give a biogenetic classification of the *Brachiopoda*[1] based on ontogenetic study.

In living specimens the subdivisions of the embryonic stage, protembryo, mesembryo, neoembryo, and typembryo may easily be made out, but since these are shell-less the work of the palæontologist begins with the phylembryonic substage, when the shell gland secretes the protegulum. From this upwards the palæontologist works on equal terms with the zoölogist, for the succeeding stages are capable of preservation, and may be compared with ancestral genera. Thus even the phylembryonic stage, or protegulum, is represented by the Cambrian genus *Paterina*, the ancestral prototype of all *Brachiopoda*.

Beecher and Schuchert[2] have also demonstrated that the *Ancylobranchia* (Terebratuloids) all go through a primitive Centronelliform stage, and that the *Helicopegmata* (spire-bearers) do the same and are for a while genuine *Ancylobranchia*. Schuchert's classification of the *Brachiopoda*, published in Eastman's translation of Zittel's *Text-Book of Palæontology*, 1896, may be taken as strictly biogenetic so far as the data now at hand make such a thing possible. And this is the only group of which we have a biogenetic classification.

[1] For correlation of stages of growth with generic changes, and for the literature on ontogeny and phylogeny of *Brachiopoda*, see papers by Dr. C. E. Beecher, Amer. Jour. Sci., Vol. XLIV, Aug. 1892, "Development of Brachiopoda," Part 2.; and Trans. Connecticut Acad. Sci., Vol. IX, March 1893, "Revision of the Families of Loop-bearing Brachiopoda;" and "The Development of Terebratalia Obsoleta Dall."

[2] Proc. Biol. Soc. Washington, Vol. VIII, July 13, 1893, "Development of the Brachial Supports in Dielasma and Zygospira."

Crustacea.—The only *Crustacea* that are useful for the study of palæontogeny are the trilobites, and since they are all extinct without leaving any descendants, modern biology can give us little help. We are thus to a greater extent than with the *Brachiopoda* thrown entirely on the ontogeny of fossils, and in this case, too, the various stages must be worked out from separate individuals. Many naturalists, beginning with Barrande, have worked on the ontogeny of trilobites, have described various stages, sometimes as larvæ, sometimes as adult genera or species, but they met with seemingly insuperable difficulties in correlating these stages with the genealogy. Dr. C. E. Beecher, however, has overcome these difficulties, presenting his results in a recent paper on "The Larval Stages of Trilobites,"[1] in which he shows that all trilobites go through a phylembryonic stage, protaspis, homologous to the protonauplius of the higher *Crustacea.* While no known genera are exactly like the protaspis, still there are several that retain many of its features. After the protaspis stage the various groups of genera develop in different directions, but all go through larval stages analogous to generic changes in their group. The protaspis itself of the later groups becomes more complicated by acceleration of development, but always retains its essential features. By means of this study Dr. Beecher has been able to give the beginning of a truly genetic classification of trilobites.[2]

Mollusca.—Of the *Mollusca* only the *Pelecypoda* and the *Cephalopoda* are of use to the student of palæontogeny, for the *Gastropoda* have not been classified in a satisfactory manner, and the larval stages even of living forms not well studied.

Pelecypoda.—Almost all that has been done in comparing genera of *Pelecypoda* with stages of growth is the work of Dr. R. T. Jackson,[3] who has shown that they all go through a phylembryonic stage, prodissoconch, analogous to the protegulum of

[1] Amer. Geol., Vol. XVI, Sept. 1895.

[2] Amer. Jour. Sci., Feb. and March 1897, "Outline of a Natural Classification of Trilobites."

[3] Mem. Boston Soc. Nat. History, Vol. IV, No. 8, 1890, "Phylogeny of the Pelecypoda."

Brachiopoda, the protoconch of *Cephalopoda* and *Gastropoda*, and the protaspis of trilobites. The prodissòconch is a straight-hinged, two-muscled, toothless, smooth-shelled, bivalve stage, corresponding to the primitive group of *Pelecypoda*. Even the monomyarian *Ostrea* goes through this dimyarian stage. Professor W. H. Dall[1] has used this and other facts in the development of the pelecypods, giving the most satisfactory classification up to this time. But from the very nature of the case, when the ontogeny of few living and no fossil forms is known, an evolutionary classification of pelecypods is impossible.

Cephalopoda.—The living dibranchiate cephalopods, *Octopus*, *Loligo*, *Spirula*, *Argonauta* and other common forms, are incapable of preserving the larval stages as fossils. The only living tetrabranchiate genus, *Nautilus*, can have its larval stages preserved as fossils, but is one of the old unspecialized types, not having changed greatly since the first nautilian shell, and consequently having no striking changes in its ontogeny.

The animals that are capable of giving the best proof of evolution are the ammonites. These branched off from the nautiloids at the beginning of the Devonian, continued increasing, diverging, became highly specialized and accelerated until their final extinction at end of the Cretaceous. Each ammonite goes through a larval history that is long and varied in direct proportion to the length of time from its period back to the Lower Devonian. Thus the *Nautilinidæ* are the first of the new stock, and their ontogeny is comparatively simple, there being no great changes from the larval up to the adult stages. The higher Devonian and Carboniferous forms go through several generic changes before they become adults, and the Mesozoic genera have still longer larval and adolescent periods, that is, longer in the sense of more complicated.

From the work of L. von Buch, Quenstedt, and others of the older palæontologists the increasing variety of forms from the goniatites of the Palæozoic to the ammonites of the Mesozoic

[1] Pelecypoda, Text-book of Palæontology, K. A. von Zittel, Revised English Edition, Vol. I, Part 1. Macmillan & Co., 1896.

was known long ago; these naturalists knew, too, that ammonites went through a goniatite stage of growth, without connecting this with evolution. By using their work we can get a comprehensive view of the development of ammonoids from the most primitive goniatites to the most highly developed ammonites, and thus construct a tentative family tree.

The simple primitive forms of the Lower Devonian branch out by the end of that age into two distinct stocks, the *Prolecanitidæ* and the *Goniatitidæ*, mostly low whorled, involute, with simple sutures and little ornamentation. Before the end of the Carboniferous some genera have already become ammonitic in the digitation of their sutures, as *Popanoceras*, *Thalassoceras*, *Pronorites*, and some have taken on ammonitic ornamentation of the shell, while the sutures remain simple and entire, as *Gastrioceras*. None of these forms, however, are very evolute, and the whorls are mostly rather low. In the Permian *Pronorites* and its descendants *Sicanites* and *Medlicottia* play an important part, *Arcestidæ* are already become important members of the fauna, the *Tropitidæ* are just beginning, while the *Glyphioceratidæ* are dying out. Some few genera still persist in the goniatitic stage, but most of them became ammonitic before the Trias was well on.

In the Trias the important groups are *Arcestidæ*, *Pinacoceratidæ*, *Tropitidæ*, *Ceratitidæ*, with numerous others less important as members of the Triassic fauna, but of great interest as ancestors of many of the chief families of the Jura and Cretaceous. In the Jura these ammonites reached their acme, branching out into very many families and subfamilies, increasing usually in complexity of sutures and variety of ornamentation. In the Cretaceous they gradually declined, dropping off one at a time until all were gone. The total number of *Ammonoidea* now described reaches about 5000, of which only a few hundred belong to the Palæozoic goniatites, the others belonging to the ammonites of the Carboniferous, Permian, and Mesozoic. Later than this no ammonoids are known.

Only simple radicles or stocks persist, but from time to time

certain genera branch off from the main stock, become highly specialized, and often give rise to so-called abnormal[1] forms, such as *Hamites*, *Baculites*, *Crioceras*, *Scaphites*, phylogerontic or degenerate genera, which do not perpetuate their race. These do not form a natural group, but are themselves even in some cases polyphyletic, as shown by their ontogeny; so far as examined their larval stages all correspond to various normal genera.

Of course there were phylogerontic genera that were not abnormal in shape; thus *Clymenia* branched off in the Upper Devonian into a variety of species, and disappeared as suddenly; *Medlicottia* reached its culmination in the Permian, barely managed to live on until the Trias, and disappeared without posterity, while the main stock of unspecialized *Prolecanitidæ* endured as long as the race. The number of phylogerontic forms increases in the Mesozoic, showing a constantly increasing tendency to become abnormal, until before the end of the Cretaceous the entire race of ammonoids becomes phylogerontic, and dies out from sheer lack of plasticity to modify itself further with changing conditions.

Such a general view or family tree of the ammonoids may be seen in any of the text-books of palæontology, especially those of Steinmann,[2] and of K. von Zittel,[3] where we get the best attempts to represent our present knowledge and ideas of the genetic relationships of ammonites. These genealogies are, however, purely tentative, based not on ontogeny but on comparison of series of adults. This would undoubtedly be the safest way if we had a perfect series of genera and species, but such a thing is unknown, and can never be obtained, on account of the incompleteness of the geologic record, and the mixing of faunas by migration in the past.

The researches of Hyatt, Branco, and Karpinsky have given us a surer way; from their work we have learned that the *Ammonoidea* preserve in each individual a complete record of

[1] J. F. Pompeckj, Ueber Ammonoideen mit Anormaler Wohnkammer. Stuttgart, 1894.

[2] Elemente der Palæontologie. 1890. [3] Grundzüge der Palæontologie. 1895.

their larval and adolescent history, the protoconch and early chambers being enveloped and protected by later stages of the shell. And by breaking off the outer chambers the naturalist can in effect cause the shell to repeat its life history in inverse order, for each stage of growth represents some extinct ancestral genus. These genera appeared in the exact order of their minute imitations in the larval history of their descendants, and by a comparative study of larval stages with adult forms the naturalist finds the key to relationships, and is enabled to arrange genera in genetic series. They were all marine, never parasitic, and so with them there is no obscuring of the record; also in the *Mollusca* generic and specific characters show in the shell better than in the soft parts; so the classification of fossil ammonites is just as good as that of living shellfish.

Although genera appeared in the order of corresponding larval stages, they did not disappear in the same order; and so their survival under favorable conditions is liable to make confusion in the record, if one depends wholly on the study of series of adults. Such forms, for instance, as *Styrites*, *Tropiceltites*, *Miltites* and others that are now known only in the Karnic zone of the Upper Trias are undoubtedly such survivals, for they still have simple goniatitic sutures, very little ornamentation, and in general are more like Lower Triassic ammonites than members of the *Tropites subbullatus* fauna. The stray *Tirolites foliaceus*, which appears in the Alps and in California in this same fauna, is another survival of a Lower Triassic type, but fortunately we do know *Tirolites* in the horizon where it belongs. If this were not the case the naturalist would be very much puzzled at finding *Trachyceras* of the Karnic horizon going through a *Tirolites* stage in its early youth.

One great drawback to this work is that the ammonite faunas of the various ages have been classified by different specialists and on different principles, but all artificial. Thus the Triassic ammonites are divided into Leiostraca (smooth shelled), and Trachyostraca (rough shelled), a classification that cannot be extended even to Jurassic groups. The Trachyostraca are fur-

ther divided into *Tropitidæ*, with long body chamber, and *Ceratitidæ*, with short chamber. But neither of these groups is monophyletic, for it is quite probable, judging from their ontogeny, that members of both groups are derived from the *Goniatitidæ*, and others from the *Prolecanitidæ*. Further, the authorities agree in deriving the *Tropitidæ* from the *Glyphioceratidæ*, but the larval stages of some of the *Tropitidæ* show the undivided ventral lobe and an unmistakable resemblance to certain *Prolecanitidæ;* other so-called *Tropitidæ* show the divided ventral lobe at an early age, and a decided resemblance to the stock of *Glyphioceratidæ*.

In the same way most authorities agree that the Trachyostraca were all extinguished at end of the Trias, and that all the Jurassic and Cretaceous ammonites, with the exception of *Lytoceratidæ* and *Phylloceratidæ*, were derived from the radicle *Psiloceras*, and this, too, in spite of the fact that many of the genera are rough shelled, and in their larval stages show marked likeness to trachyostracan genera. Any naturalist can convince himself of this by looking at the young stages of Jurassic ammonites figured by Quenstedt.[1] Quite recently Professor W. Waagen[2] has called attention to the likeness of certain Trachyostraca to Jurassic genera, and indicated the probability of genetic relationships. But Mojsisovics[3] says that these similarities have nothing to do with relationship, but are purely "convergence phenomena," whatever that may mean. Resemblance of adults of Triassic and Jurassic forms might with some reason be ascribed to this mysterious agency, but surely no biologist would thus explain away the resemblance of larval and adolescent stages of Jurassic ammonites to adult Trachyostraca of the Trias. There was some excuse for such opinions as long as the fauna of the upper Trias was not well known, and there was apparently a great break in the series of ammonites. But after the appearance of the monographs of G. von Arthaber, Diener,

[1] Ammoniten des Schwäbischen Jura.

[2] Pal. Indica, Salt Range Fossils, Vol. II, p. 122.

[3] Das Gebirge um Hallstadt, Bd. II, p. 265.

Mojsisovics and Waagen,[1] on the Triassic faunas of the Alps, Himalayas, the Salt Range of India, and Siberia, there is no longer any such excuse. Ancestral types, long predicted by larval stages of Jurassic ammonites, may be seen in these works, as, for instance, *Tropiceltites*, which is exactly like the neanic stage of *Amaltheus;* but the great variety is confusing, and correlation difficult, on account of unsatisfactory classification.

The only solution of the problem is to classify genetically the Palæozoic goniatites, and from them work upwards into the Permian and Lower Triassic ammonites. These older groups have simpler larval stages, are not very greatly accelerated, and repeat clearly their ancestral history. When this is done the radicles will all be known, and when we know the stock of the tree, the branches that came off in the higher Trias, Jura, and Cretaceous will offer no difficulties. The most systematic attempt to do this is Haug's paper, "Les Ammonites du Permien et du Trias;"[2] but his classification is based wholly on the character of the sutures, and neglects other characters, such as sculpture and shape of the whorls. Thus Haug[3] places *Eutomoceras* with the prionidian family *Trachyceratidæ*, disregarding its ontogeny, which places it undoubtedly with the *Tropitidæ*. But no classification based entirely on one character can be truly genetic. Hyatt[4] in his monographs on the ontogeny of ammonites has shown us the way; Branco by his studies of the larval stages of ammonoids has accumulated a great mass of accurate data that can be used with confidence even by the student that rejects his theories as to classification. And Karpinsky, by using the methods and principles discovered by these naturalists, has worked out the genealogy of one of the chief stocks of the earlier ammonites.

[1] For the literature on Triassic faunas see JOUR. GEOL., Vol. IV, No. 4, J. P. SMITH, "Classification of Marine Trias."

[2] Bull. Soc. Géol. France, II Ser., Vol. XXII. 1894, No. 6.

[3] Op. cit., p. 408.

[4] Bull. Mus. Comp. Zoöl., Vol. III, No. 5, 1872; and Smithsonian Contrib. to Knowledge, "Genesis of the Arietidae," and other papers.

This way lies the truth, and not in groundless speculations such as many students of cephalopods are prone to indulge in.

Method of working.— In order to succeed, one must select material with great care, preferably limestone that is soft but not so weathered as to crumble, nor so brittle as to shatter. One's finger nail and some steel dental chisels are all the tools needed for breaking off the outer whorls of young ammonites. A microscope with thirty diameters magnifying power is the most satisfactory, although higher powers are occasionally needed. For studying surface markings a strong pocket lens is usually sufficient; the specimen should then be placed dry on white cardboard. For observing the sutures, or shape of the whorls, the specimen should be placed on cardboard in a drop of water, spread out so as not to distort the object. The water, being slightly viscous, will also hold the small object in any position. For taking measurements a micrometer eyepiece is needed, especially in drawing, for the *camera lucida* is not very satisfactory for drawing opaque objects. Sections can easily be cut by grinding with emery powder on a glass plate.

The accompanying illustrations will give an idea of how the facts are ascertained. A number of well-preserved adults of a species are selected, and the outer coils are pulled off piece at a time under water, until a complete series is obtained, representing every change in growth. All the pieces of whorls are preserved, but often it is possible to have a complete series in one specimen. The individuals representing stages of growth are kept separate, in small glass tubes attached to cards for labels, on which are noted the measurements of the specimen, stage of growth, and such other facts as are wanted for ready reference.

On plate *A* are shown the results of some work of this character. The species selected was *Schloenbachia* aff. *chicoensis* Trask, from the upper Horsetown beds, top of Lower Cretaceous, from Phœnix, Oregon. Fig. 1 shows the protoconch with part of the first whorl drawn as if unrolled. The protoconch is phylembryonic, representing the primitive ammonoid; the first suture, angustisellate, with narrow lateral lobes and saddles, is

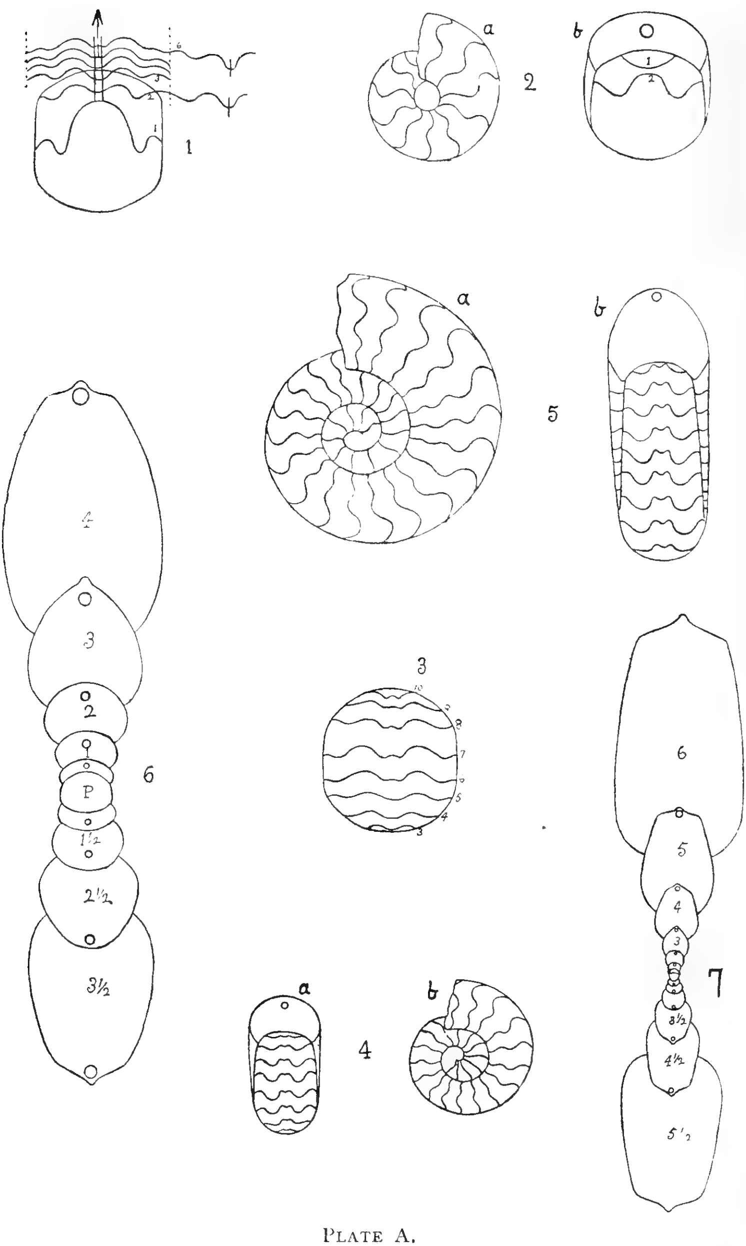

Plate A.

ananepionic; the second suture with the abdominal lobe is metanepionic, and represents the ammonoid radicle *Anarcestes;* the third and fourth sutures correspond to *Tornoceras* and *Prionoceras;* the fifth suture is a transition from *Prionoceras* to *Glyphioceras;* and the sixth with the divided ventral lobe represents *Glyphioceras.*

Fig. 2 shows the larval stage, at diameter of $0^{mm}.68$, three-fourths of the first whorl. It has a low broad involute whorl, with divided ventral lobe, one lateral lobe, and another on the umbilical border. This stage is paranepionic, and is like the older species of *Glyphioceras.*

Fig. 3 shows the development of the sutures from the third to the tenth, on a specimen of diameter $0^{mm}.64$.

Fig. 4 shows the advanced *Glyphioceras* stage, with lobes and saddles, well developed, at diameter of $1^{mm}.20$; the second lateral lobe already begins to show on the umbilical shoulder. This stage is transitional to *Gastrioceras.*

Fig. 5 shows the end of the paranepionic stage, corresponding to *Paralegoceras*, at $2^{mm}.25$ diameter; the umbilicus widens, the whorls become higher and narrower, and a third lateral lobe appears on the umbilical border. The sutures still remain goniatitic, but in the next stage, ananeanic, ammonitic ornamentation, in the shape of a keel, appears at $2^{mm}.70$; and at $3^{mm}.20$ diameter the first lateral saddle becomes indented, and the adolescent stage is well along.

Fig. 6 shows a cross section through the center, diameter $6^{mm}.25$, four whorls, paraneanic. The inner whorls are low and broad, and the later ones become successively higher and narrower in proportion.

Fig. 7 shows a section through the protoconch, diameter $22^{mm}.25$, six whorls, adult stage; the relative increase of height of the whorls and the squaring of the abdominal shoulder is quite marked as the adult stage advances.

On these figures may be seen increase in number of lobes and saddles, change in position of the siphon from median to external, and the development of the whorls, in height, width, and involution.

By following this method on suitable material the complete ontogeny of any species may be worked out. In order to work out the phylogeny of any form it is necessary to combine this with comparative study of antecedent genera and species. When this is done for all the *Ammonoidea*, their genealogy will be more perfectly known than any other family tree possibly can be.

PLATE *A*.

FIG. 1. Protoconch of *Schloenbachia*, showing the first six sutures of the attached coil. Enlarged thirty times.

FIG. 2. Larval stage of *Schloenbachia*, diameter $0^{mm}.68$; thirty times enlarged; three-fourths of first whorl. *2a*, side view; *2b*, front view.

FIG. 3. Larval stage of *Schloenbachia*, diameter $0^{mm}.64$; thirty times enlarged. Showing sutures from the third to the tenth. From above.

FIG. 4. Larval stage of *Schloenbachia*, diameter $1^{mm}.20$; fifteen times enlarged. One and a half whorls. *4a*, front view; *4b*, side view.

FIG. 5. End of larval stage of *Schloenbachia*, diameter $2^{mm}.25$; fifteen times enlarged. *Paralegoceras* stage. *5a*, side view; *5b*, front view.

FIG. 6. Cross section of *Schloenbachia*, diameter $6^{mm}.25$; fifteen times enlarged; four whorls. Adolescent stage. The protoconch is seen in the center *P*.

FIG. 7. Cross section of *Schloenbachia*, $22^{mm}.25$; three and a half times enlarged; six whorls. Adult stage.

JAMES PERRIN SMITH.

STANFORD UNIVERSITY,
California.

EDITORIAL.

THE press announce the auspicious starting of Andrée on July 11. The result of this first experiment in Arctic aërial navigation will be awaited with unusual interest. If Andrée shall succeed in floating at a suitable elevation for even a week and shall make good his return, he can scarcely fail to bring back data of vital importance. It is of trivial consequence whether he passes near the pole or not, and his geographical discoveries are uncertain, for his course may not take him over new territory, but he will determine the course pursued by the body of air in which he floats if he is able to keep his location, of which there is little ground for question. The course pursued by a given body of air in a region which bears such critical relations to the whole system of atmospheric circulation is a matter of radical importance. Observers at fixed points upon the earth can only determine the transient local direction of passing bodies of air. They cannot directly demonstrate the actual circulation. They can only infer it from a combination of local observations. But the actual circulation can be determined by means of the balloon floating with the body of air, subject, of course, to certain obvious qualifications, particularly those that relate to vertical movements. Andrée's trip should therefore bring forth data of vital consequence to all hypotheses relating to polar atmospheric circulation. Among these hypotheses is one suggested by the ice drift which the writer has never seen in print, and which pointedly illustrates the possible value of Andrée's experiment.

It is now well known that the free ice off the Siberian coast drifts westward until it impinges upon the east coast of Greenland, when it is diverted to the south, but on reaching Cape

Farewell it rounds to the westward and even northward, until it is again arrested by Baffin Land and the American mainland, and forced southward. The marvelous trip of Nansen has given this a heroic demonstration not likely to be questioned. It is also known that the ice fields north of Greenland and Grinnell Land press hard against the coast, and crowd through the straits between these lands in a southwesterly direction. It is also known that the ice presses hard on the north side of the Parry Islands and pushes southward and eastward, effectually blocking all the straits between them as well as Jones Sound on the east. It is also known that Banks strait and McClintock channel, trending from the northwest to the southeast, are effectually blocked by the persistent jam of the ice crowding in *from the northwest.* It is the strong and unremitting jam of ice into this channel that has rendered all attempts at the northwest passage abortive. Correlating these movements, it appears that there is a common drift towards some point not far distant from the magnetic pole.

Now it is well recognized that this ice drift is essentially controlled by the winds. The sea currents are, to be sure, a factor, but, except as they are an expression of wind action, they seem to be relatively ineffectual. These movements have therefore suggested the hypothesis that the pole of the winds is not identical with the pole of the earth, but lies somewhere in the quarter toward which the ice drift tends to concentrate itself. This is based on the assumption that the supposed spiral course of the winds about the atmospheric pole tends to concentrate the ice at it. It is not difficult to find data in lower latitudes that fall in with this hypothesis, as, for instance, the predominant course of mid-latitude cyclones in this country and the trend of the Asiatic arid belts.

This is not the place to argue the hypothesis nor to set forth the numerous and important corollaries that spring from it. A sufficient number of significant corollaries will doubtless suggest themselves to indicate its importance, *if true.* The purpose in hand is to show how decisive the determination of the course

of any representative body of air in those regions must be on such a hypothesis and on similar hypotheses. If Andrée's balloon follows a spiral course (cyclonic gyrations aside) whose center lies in the quarter toward which the ice concentrates, the hypothesis will receive encouragement. If not, it becomes a hopeful candidate for the limbo of unsupported inferences. The reverse may be said respecting the common assumption of a strictly axial whirl, but as that rests on general probabilities it does not so well illustrate the critical value of an actual test of the movement of the air.

On quite other grounds it might equally well be affirmed that the navigation of the Arctic air by balloons will, if found practicable, have its own peculiar function which neither ship nor sledge can supply. T. C. C.

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THE state of Missouri has recently had deep disgrace thrust upon it by the removal of the efficient director of the Geological Survey and by the appointment of men to its care and conduct who possess, according to information that we deem trustworthy, not only no competency to perform their duties, but not even a plausible semblance of competency. These appointments have apparently no other motive than the conferring of personal or political favors. No causes of complaint, we are informed, were even alleged against the previous conduct of the Survey or against the officials in charge of it. The scientific public has had ample demonstration of the vigor and energy with which the Survey has been prosecuted, the promptness with which its results have been published, and the adaptation of the work to the development of the economic as well as scientific resources of the state. It appears, therefore, that the moneys appropriated by the state of Missouri for the laudable purpose of investigating and advertising its resources and of informing its people concerning their own sources of material and intellectual wealth are being virtually diverted from the purposes specifically indicated by the statute of the state, and are being used for the personal and political interests of the

governor and his friends in the form of payment for worthless services. We are not sufficiently informed in the technicalities of law and the processes of the courts to know how legal action in a case of this kind can be instituted and maintained, but if the appointees are as obviously incompetent as information indicates, they are simply consuming the funds of the state to no purpose save their own, and we think that an effort should be made to procure a formal declaration by the courts whether this is not a virtual embezzlement, and if so, to secure the award of the proper punishment. If there is now no way of compelling a governor to respect the laws of a state and the purposes of its statutes, a way should be provided. T. C. C.

REVIEWS.

The Bedford Oölitic Limestone of Indiana. By T. C. HOPKINS and C. E. SIEBENTHAL. Extr. 21st Ann. Rep. Dept. of Geology and Natural Resources (of Indiana). W. S. Blatchley, State Geologist, Indianapolis, 1896.

All of the older geological maps of Indiana show the various rocks across that state in broad, sweeping lines, and that, too, in spite of the fact that the rocks are everywhere nearly horizontal and have been deeply trenched by the streams. The last two reports of State Geologist Blatchley have shown a great improvement in this respect—the maps by Hopkins and by Kindle in the twentieth report and those by Hopkins and Siebenthal in the twenty-first report are by far the best that have yet appeared of the areas represented, showing, as they do, the dendritic form of outcrop to be expected.

From the earliest to the latest of the Indiana reports, almost every one has had something to say of the well-known oölitic limestone; but hitherto there has been no report on this rock that could lay claim to being a systematic description and discussion of it. The present report bears internal evidence of having been prepared under pressure, but it is nevertheless a highly creditable and valuable piece of work, and by far the best report ever made on the Bedford stone. The maps show a vast amount of field work, and exhibit for the first time the distribution of this valuable building stone. We are glad to see that the authors do not feel it incumbent upon themselves to "puff" the Bedford stone. This and every other good building stone, once it is given a chance, may be trusted to take care of its own reputation without any such help from geologists as that quoted on page 323. Evidently some people think the truth can be improved upon. What Mr. Hopkins says is certainly as much as reasonable people can ask. "The Bedford oölitic limestone can unhesitatingly be recommended as one of the most durable building stones on the market, where not exposed to the action of acids. It is fireproof up to the point of cal-

cination, in which property it can be surpassed by no other limestone and but few other building stones, as very few are absolutely fireproof." The list of the more important buildings made of the oölitic limestone at the end of the report shows that it is already used in almost every state of the Union, in which use the cities of Chicago, Indianapolis, and New York lead.

Statistics show that over six million cubic feet of Bedford stone was quarried in 1895, worth more than a million and a half of dollars; 1784 men were employed that year in the quarries, to say nothing of those engaged in stone-cutting, transportation, and building. The work includes valuable statistics, tests, and analyses, and many instructive photographs of quarries, machinery, exposures, and buildings, and closes with a bibliography of oölites in general and of the Bedford stone in particular.

In the way of minor criticisms abandoned quarries are indicated on the maps, but not those in operation; while the lithographing of the maps is neatly done, the distinctions between formations might have been clearer in some cases without increasing the cost of the maps.

The most serious criticism of the report is one for which the authors are not responsible, but it is one that unfortunately applies to many of our state reports, and is referred to here rather on general principles than on account of it being especially applicable to the present case; we refer to the short time allowed for its preparation. No matter what the worker's aims, intentions, or abilities may be, behind him is the state geologist demanding much work in a short time and at little expense; the state geologist imagines the legislature is making the same demands on himself, while behind the legislature are the people asking for practical results. In our national surveys we have pretty much the same state of affairs—a constant demand for something to show for the money used. As a matter of fact, the practical results of hasty work cannot be the best results. Haste in work of this kind, like haste in other things, is waste. It is our decided opinion that no member of a legislature or of Congress will object to allowing a state or a national geologist time to do good work if only the truth is placed fairly before him. Last year we had a valuable paper by Professor Hopkins on the carboniferous sandstones of Western Indiana; this year we have the present report on the Bedford stone, and some other year we shall have reports on other building materials of Indiana. Thus the matter that ought to have formed a single mono-

graph is scattered through several volumes, disconnected, and therefore less known and less valuable either to the state or to the general public. Nevertheless, the state geologist is to be congratulated on his selection of men to do this work and on the results obtained in so short a time, for it is unquestionably one of the very best reports made in this country upon building stones. J. C. BRANNER.

The Ancient Volcanoes of Great Britain. By SIR ARCHIBALD GEIKIE, F. R. S. Macmillan & Co., London and New York, 1897.

This work, as Sir Archibald Geike states in the introduction, is the outgrowth of his presidential addresses before the Geological Society of London in which he sketched the volcanic action in ancient times in Great Britain, whose record is left in the igneous rocks of several epochs from pre-Cambrian to Tertiary. No other part of the earth, so far as now known, presents within a comparatively small area such evidences of oft repeated volcanic action through so great a period of time. Commencing in pre-Cambrian times with three definitely localized volcanoes, the series is found to have extended through the Cambrian, Silurian, Devonian, Carboniferous, Permian and Tertiary times. The importance of the evidence furnished by so extensive a series of periods of volcanic activity as to the cause of volcanic action, and the source of the materials erupted must be apparent.

Its bearing on the question as to whether volcanic phenomena differed materially in the earlier periods of geological history from those of recent date, is also most valuable. And it is to be noted that the conclusion reached is that they are alike. The presentation of the facts known about these ancient volcanoes involves a description of rocks that were formed in various situations in the volcanoes; upon their surface, within their mass or within rocks beneath or about them; and which were subjected during the ages to processes that have modified their internal character and sometimes their external form. In order that these descriptions may be understood by the general reader the first chapters of the work are devoted to a consideration of general principles and methods of investigation. The nature and causes of volcanic action, and the phenomena connected with modern volcanoes are briefly noted. Considerable space is given to the characteristics of

ancient volcanoes, the nature of the material erupted, and the several types of volcanoes. Underground phases of volcanic action are also described; and the effects of subsequent denudation in exposing the rocks and their influence on the topography and scenery are discussed.

The major part of the work treats in detail of the volcanic phenomena connected with each period of activity, beginning with that in the pre-Cambrian time. Upon petrographical grounds the most ancient Lewisian gneiss, corresponding to what is often called Archæan, is considered to have been originally a mass of various eruptive rocks. Although they have been subjected to great mechanical deformation, the present banded structures are connected with the original igneous condition of the rocks. They were probably underground lavas, possibly connected with extrusive bodies. With these rocks are associated dikes of basic and acid rocks. Rocks of volcanic origin undoubtedly occur in the Dalradian schists of Scotland and in the gneisses and schists of Anglesey. The Uriconian, Malvern, and Charnwood Forest volcanic rocks are all of pre-Cambrian age. The volcanoes of Cambrian time occurred in South Wales, North Wales, Malvern Hills, and Warwickshire; those of Silurian time occurred in Wales, North of England and in Scotland, and Ireland; partly in the Lower, partly in the Upper Silurian. Volcanic activity was pronounced in Middle Devonian times but in certain districts extended into the Upper Devonian. In the period of the Old Red Sandstone there existed numerous centers of volcanic activity. In Lower Old Red Sandstone time they extended from Shetland to the Chevoit Hills in England and even to Lake Killarney, and from the coast of Berwickshire on the North Sea to near Lough Erne in the north of Ireland. They are less numerous in Upper Old Red Sandstone time, occurring in the southwest of Ireland and the north of Scotland. The Carboniferous age was marked by prolonged volcanic activity in Scotland and by restricted activity in England and Ireland. The volcanoes were partly of the plateau, partly of the puy type, accompanied, of course, by intrusive bodies. The Permian volcanoes of Scotland and England are much less important.

Four fifths of the second volume are devoted to the volcanoes of Tertiary time, for the reason that they are the most recent and their rocks are the freshest and most abundant. They occur along the west coast of Scotland and the northeast of Ireland. The dikes, plateau, and fragmental rocks are described in detail, and an account of the mod-

ern volcanoes of Iceland is introduced by way of illustration. The eruptive vents and the intrusive bodies, as sills and bases, both basic and acid, are also described.

The work closes with an account of the subsidences and dislocations of the plateaux and the effect of denudations. The final chapter consists of a brief summary together with the following general deductions: The distribution of the centers of volcanic activity has been along the western side of the country in a north and south line. The persistency of volcanic activity in this region and its restriction to particular localities are some of its most marked features. The sites of volcanic vents in Britain do not seem to have been determined by any obvious structures in the rocks now visible. Volcanic phenomena cannot be regarded as mere isolated and incidental features in the physics of the globe. They are intimately connected with profound terrestrial movements. They have been essentially uniform since the beginnings of geological time. In extent and rigor the earliest eruptions of which we have records did not differ in any important respect from those of the present time. However volcanic energy has not manifested itself uniformly throughout geological time. There have been periods of maximum and of minimum effectiveness. The character of the volcanic rocks and the general sequence of their eruption have been the same with slight modification for all the periods of activity in this region.

J. P. IDDINGS.

The Submerged Valleys of the Coast of California, U. S. A., and of Lower California, Mexico. GEORGE DAVIDSON, A.M., PH.D., Sc.D. (Member of the National Academy of Sciences, etc)., Proc. Calif. Acad. Sci. Third Series, Geology, Vol. 1, No. 2. With Nine Plates. San Francisco, 1897.

This paper gives a brief description of the Pacific coast from the southern extremity of Lower California to the Strait of Fuca. The general character of the coast, south of Cape Mendocino, is bold and rocky, reaching considerable elevations within a few miles of the shore. These coastal ranges are broken by valleys and plains of varying width which may or may not correspond to the submarine depressions described.

Bordering the coast from about Cape Mendocino southward there is generally a submarine platform, having an average width of ten miles,

and extending to the 100-fathom curve. Beyond this platform the descent is usually rapid, 2000 fathoms being reached in from 35 to 100 miles from the shore.

In this 100-fathom platform the submarine valleys are found, heading either close to the shore or only a short distance out, and extending to a depth of from about 100 to at least 600 fathoms. These valleys vary largely in direction, form, and character of the bottom. Four valleys are found off the coast of Lower California and seventeen are described from the California coast. They are most numerous near the southern end of the state, and near Cape Mendocino, where four of considerable size are found within a stretch of twenty miles. These four are peculiar in heading under the highest parts of this strip of coast, while the majority of the channels are opposite valleys or openings in the coast ranges. All of the valleys are described in some detail and are well shown by submarine contours on the accompanying maps. North of Cape Mendocino no submarine valleys have been noted with the exception of one indicated near the mouth of the Columbia River.

Although this paper is of importance to geologists, no direct attempt is made in it to give the geological bearing of the facts stated. One assumption, which is open to criticism, is made by the author in using the term "submerged" where he formerly used "submarine," to describe these valleys, since it is doubtful whether all of them can be considered as submerged channels. The studies of the present writer on the submarine topography of a part of the California coast have led him to the conclusion that no general statement can be made as to the origin of these valleys. They may be due to one or more of three causes — either (1) they are structural, due to faulting or folding; or (2) they are due to the forces of subaërial erosion, and therefore are strictly "submerged valleys;" or (3) they may possibly be due to subaqueous erosion in delta deposits. Under which of these heads a given valley should be placed must be determined by a special study not only of the submarine features but of the topography, stratigraphy and structure of the neighboring land area, and possibly also of the characters of the shore-currents at that point.

W. S. Tangier Smith.

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THE

JOURNAL OF GEOLOGY

SEPTEMBER-OCTOBER, 1897

THE NEWARK SYSTEM OF NEW JERSEY.[1]

THE Newark system extends across the northern part of New Jersey, forming a belt which is about thirty-two miles wide along the Delaware River, while its width at the New York state line is about fifteen miles. The southeastern boundary from Trenton northeastward to Staten Island is for the most part formed by the overlying Cretaceous beds. Near Trenton, however, the underlying Philadelphia gneiss outcrops for a few miles. The waters of the Kill von Kull, New York Bay and Hudson River form the boundary from Staten Island northward. The northwestern boundary is irregular and is formed entirely by older rocks, — crystallines and Palæozoic shales and limestones. This paper has to do with that part of the area lying southwest of a line drawn from Metuchen, through Plainfield to Peapack.

Topography.—In general the area is a gently rolling plain, having an average elevation of 100 to 250 feet A. T. The plain is interrupted by the valleys and trenches of the present streams and hills, ridges and plateaus of harder rock. The largest of these is the Hunterdon plateau. Commencing at Raven Rock on the Delaware River a prominent escarpment extends northeastward, past Flemington, where it bends north and then northwest, finally terminating near Lansdown about eighteen miles from the

[1] Published by permission of the State Geologist of New Jersey. For a more detailed statement of all the facts upon which this paper is based, see Annual Report of the State Geologist for 1896, pp. 25–88.

Delaware River. Northwest of this line is a broad plateau, having an average elevation of about 600 feet. It extends westward into Pennsylvania, being dissected by the Delaware to a depth of 400 to 500 feet. Its highest part is along the south and east, about a mile back from the top of the escarpment. Thence it declines in elevation very gently northward and westward. The escarpment is most marked in the vicinity of Flemington, where the contrast in hardness between the rocks of the plateau and of the low ground is the most marked.

Sourland plateau extends from Lambertville on the Delaware, northeastward for seventeen miles. It has an average width of four and a half miles and varies in height from 450 to 560 feet. The backbone of the plateau is a belt of trap rock, a mile in width, but the hard sandstones and argillites on either side rise nearly to the same elevation. In the vicinity of Hopewell and northward, the plateau is separated from the low plain to the southeast by an escarpment varying from 200 to 400 feet in height. Other masses of trap rock forming minor hills and ridges rise from 200 to 500 or 600 feet above the general level. Along the northwestern boundary also there are several marked elevations due to massive quartzite conglomerates.

THE ROCKS.

It has been found possible to divide the sedimentary rocks of the Newark system into three subdivisions.[1] These are not based upon palæontological evidence, since fossils are too few to be used for this purpose, but on lithological differences, which permit the establishment of recognizable horizons. While fully aware of the dangers attending the use of lithological characters in correlation, the author is confident that in this case they have been reduced to a minimum, owing to the care with which the beds have been traced step by step. The beds of the three series

[1] Practically all the outcrops and sections — many hundreds in number — have been examined and plotted. All the roads and nearly all the stream beds have been traversed. So monotonous are the beds that it is only by this detailed work that there is any possibility of detecting and tracing the structural complications.

grade into each other vertically through transition zones several hundred feet in thickness, so that it is not always easy to delimit them exactly in the field. Moreover, all three members lose to a great extent their distinctive characteristics when traced along the strike of the northwestern boundary north of Pittstown. With these exceptions, however, the beds of each division are *en masse* quite unlike and readily separable from each other. The accompanying map shows their location and the main faults by which they are repeated.

Stockton series.—The basal beds of the system are found at Trenton where they rest unconformably upon the older crystalline rocks. They consist of (*a*) coarse, more or less disintegrated arkose conglomerates; (*b*) yellow, micaceous, feldspathic sandstone; (*c*) brown-red sandstones or freestones, and (*d*) soft red argillaceous shales. These are interbedded and many times repeated, a fact which indicates rapidly changing and recurrent conditions of sedimentation. Although there are many layers of red shale in this subdivision the characteristic beds are the arkose conglomerates and sandstones, the latter of which afford valuable building stones.

In addition to the cross-bedded structure which often prevails in the sandstones, ripple-marks, mud-cracks and impressions of rain drops occur. The rapid alternation from conglomerates to shales and *vice versa*, the changes in composition in individual beds, the cross-bedding, ripple-marks, etc., all indicate very clearly that these beds were deposited in shallow water in close proximity to the shore. The bulk of the material of which they are composed was derived from the crystalline rocks on the south and southwest.

Owing to the tilting and faulting, the Stockton beds outcrop in several belts as shown by the map. The most important areas are (*a*) the Trenton area, which extends northeastward to Princeton beyond which place it is mostly buried by Cretaceous and Jamesburg deposits; (*b*) the Hopewell area along the southeastern face of the Sourland plateau, where the upper part of the series has been brought to the surface by a fault; (*c*) the

Stockton area, where the upper layers are exposed in numerous quarries near the village of Stockton; (*d*) the area north of Flemington.

In the Stockton area the upper limit of the series extends along the crest of the escarpment of the Hunterdon plateau, the steep slope being formed by the upper beds of Stockton series which are here predominantly red shales, with an occasional sandy layer. Northeastward this belt is terminated by a great fault which crosses the beds obliquely so that the belt becomes narrower and finally pinches out a few miles southwest of Flemington. Within this area the more massive conglomeratic beds form three broad low ridges, each of which terminates somewhat abruptly at the fault.

An important modification was found in the character of this series within the area north of Flemington. Where the rocks first occur near Flemington, they consist of coarse arkose sandstones and red shales. The transition here to the overlying series is through sandy shales similar in texture and thickness to the uppermost layers northwest of Stockton. As the northwestern border of the formation is approached the arkose conglomerate and sandstones give place to red shale beds or sandstones and conglomerates of a different type. For a distance of four miles southeast of Clinton the basal beds of the formation rest unconformably upon Silurian shales, limestones, and still older quartzite and gneiss. Material from these formations has determined the local character of the Newark beds. In place of the free-splitting brown and red sandstones, there occur coarser beds made up largely of thin bits of shale, and small quartzite pebbles. Although the Stockton beds rest in part upon the limestone and gneiss, these rocks occur but rarely in this part of the newer formation. Their comparative absence has not been satisfactorily explained.

Lockatong series.—Above the Stockton beds there is a series of hard, dark-colored shales and flagstones, which I have called the Lockatong beds from the name of the creek in Hunterdon county, along which they are best exposed. They consist of

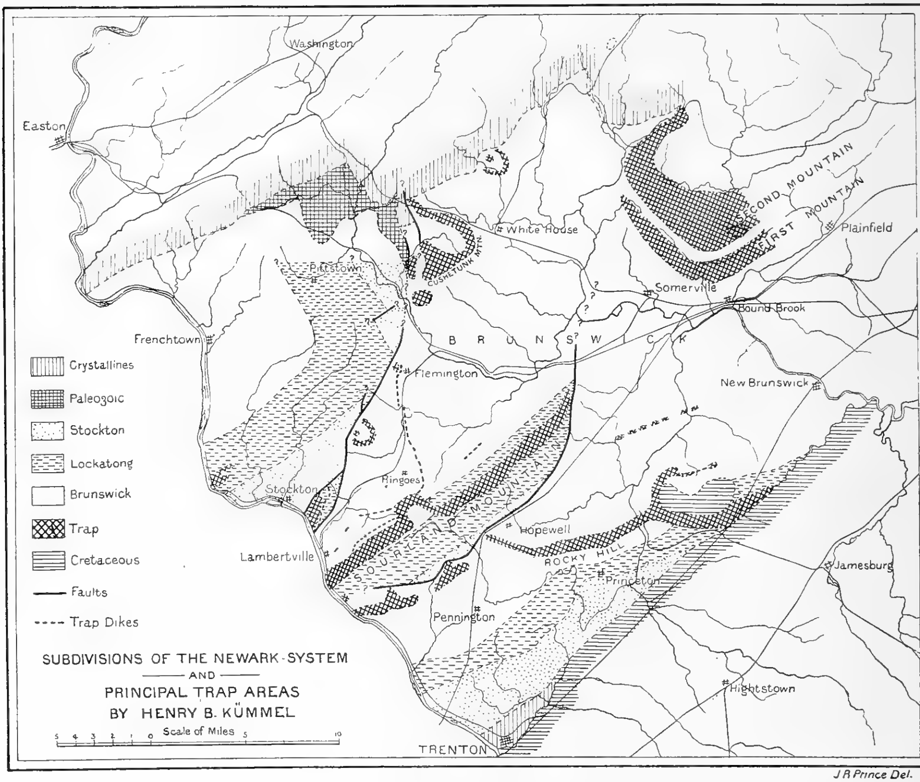
(*a*) carbonaceous shales, which split readily along the bedding planes into thin laminæ, but have no true slaty cleavage; (*b*) hard, massive, black and bluish-purple argillites; (*c*) dark gray and green flagstones; (*d*) dark red shales approaching a flagstone; (*e*) and occasional thin layers of highly calcareous shales. There are all gradations between these somewhat distinct types, so that the varieties of individual beds are almost countless. Some of the argillites are specked with minute crystals of calcite and the faces of joint planes and cavities are frequently covered with deposits of the same mineral. Minute crystals of iron pyrites occur frequently in some layers, but apart from them and the calcite, secondary minerals were not found, macroscopically, in these beds.

Both ripple-marks and mud-cracks occur at all horizons in the Lockatong beds, showing that shallow water conditions prevailed throughout the time of their deposition. On the other hand, the absence of strong currents or violent shore action is indicated by the extreme fineness of the material.

Owing to the faulting these beds occur in several well-marked belts, in each case overlying conformably the Stockton series. The first belt reaches the Delaware between Wilburtha and Washington's Crossing, and extends northeastward through Ewingville, Lawrenceville, and Princeton, where there are several large quarries in the argillite beds. East of the Millstone River the limits of this belt cannot be determined accurately owing to the veneer of the Jamesburg formation, but from a few scattered outcrops and borings, these beds probably cross the Raritan River below the mouth of Lawrence Brook.

The Lockatong beds occur again along the southeastern side of the Sourland plateau, resting upon the narrow belt of Stockton sandstones which forms the escarpment of this upland. From the Delaware River to the village of Newmarket the upper limit of the beds lies a little below the trap sheet which forms the backbone of the upland. The interval between them is occupied by the softer red shales of the third series, which are somewhat metamorphosed near the igneous rock. Northeast of New-

market, owing to a sharp curve in the trap sheet by which it crosses the beds nearly at right angles, the Lockatong beds occur on both sides of the trap, their upper limit being about 1760



feet above the latter. The plateau, which owes its elevation to the hardness and durability of the argillite flagstones and trap, is terminated on the northeast by the fault.

The most extended outcrop of the Lockatong beds occurs on the Hunterdon plateau, in the region known as "the Swamp." As shown on the accompanying map the width of the outcrop is greater here than elsewhere due to diminished dips, 10° to 13° here as against 15° to 20° on the Sourland plateau, and the belt

forms a broad regular curve, due to the synclinal structure. The height of the Hunterdon plateau is due to the wide outcrop, curving strike and hardness of these rocks and of the upper layers of the Stockton series, all of which have retarded greatly the forces of denudation, so that whereas the adjoining softer rocks have been reduced to an average elevation of under 200 feet, this belt has an elevation of from 500 to 700 feet.

Along the Lockatong and Wickecheoke creeks, which have deeply incised the margin of the plateau, rapids and falls abound. Hard dark red flags are interbedded with the black argillites, and some of the more pronounced beds can be easily traced for several miles along the curving strike. This was done in so many cases at different horizons as to render it almost certain that this belt is not traversed by faults of any magnitude. The width of outcrop is due to the great thickness and the gentle dip.

Modification of the Lockatong beds.—Important modifications were found to occur in this series near the northwestern boundary. The shales and argillites grade into sandstones, and these into coarse conglomerates. Some layers become slightly arkose. This change occurs *along the strike*, and is accomplished within six miles or less. Within a mile and one-half along the strike from the point where the first pebble-bearing layers were noted, the series is composed chiefly of massive conglomerates in which the pebbles are frequently six or eight inches in diameter. Since not only the Lockatong beds but the next higher series also grade into these marginal conglomerates, it will be well to postpone further consideration of them for a brief space.

The Lockatong beds give rise to a rather heavy wet clay soil. The surface is quite thickly strewn with slabs of argillite and flagstone, and on the slopes outcrops are generally abundant. Except in places favorable to the accumulation of the soil from higher slopes its depth is generally less than five or six feet.

The Brunswick shale series.—I have applied this name to the great thickness of soft shales and occasional sandstone layers

which overlie the Lockatong beds, and which are so well exposed in the valley of Raritan, particularly near New Brunswick. They are predominantly red in color, although a few purple, green, yellow, and black layers occur. In general this series consists of a monotonous succession of very soft argillaceous red shales which crumble readily to minute fragments, or split into thin flakes. Much of it is porous, the minute, irregular-shaped cavities being often partially filled with a calcareous powder. Calcite veins and crystals are common in some layers. Locally lenticular masses of green shale occur in the red. In size these range up to a foot or two in diameter, and vary in shape from nearly spherical to lenticular masses, narrowing down to thin sheets along cracks. They are undoubtedly due to chemical changes resulting in the leaching of the shale.

Although the majority of this series are soft red shales, there are some hard layers, chiefly near the base, and occasional beds of fine-grained sandstone and flagstones, some of which afford valuable building material. Massive conglomerates along the northwestern border are in part the shoreward correlatives of the red shales.

Evidence that the shales were deposited in shallow water is abundant. Ripple-marks, mud-cracks and rain-drop impressions occur at many horizons. In some quarries imprints of leaves, of tree stems, or the stems themselves are frequently found. The numerous reptile tracks which have made the Newark beds famous occur chiefly in this subdivision. Typical exposures occur along the Raritan River, particularly near New Brunswick.

The Brunswick beds underlie all the region under discussion except that occupied by the Lockatong and Stockton beds and the trap rocks. This area is considerably more than two-thirds of the whole, partly because of the great thickness of the series and partly because the beds have been bent into broad, gentle folds. Standing on the northern end of Sourland plateau one has a magnificent view of the low plain formed on the Brunswick shales, chiefly in the Raritan valley, of the trap ridges which interrupt its continuity and of the enclosing highlands. To the

west is the Hunterdon escarpment, forming the westward limit of the Brunswick shales and marking the line of a great fault, by which the rocks of the plateau have been uplifted several thousand feet.[1]

Thirteen to sixteen miles to the north across the low shale plain are the gneiss highlands, and eight miles northeastward are the curving level crests of the Watchung trap ridges which are interbedded with the Brunswick shales, and beyond which the shale lowland extends. No high ground meets the eye to the east toward New Brunswick thirteen miles away, but to the south rises the Rocky Hill trap ridge, at one point deeply cut through by the Millstone, and there marking the approximate limit of the Brunswick shales. To the southwest there stretches away on either side of the narrow plateau on which we stand, a strip of rolling lowland, likewise underlain by the Brunswick shales.

These rocks also outcrop above the Lockatong series in the northern part of the Hunterdon plateau. They are exposed in high bluffs along the Delaware above and below Frenchtown. It was found that the shales of this area when traced along their strike towards the margin of the formation became rapidly coarser, passing along some horizons into massive conglomerates. It will be remembered that similar changes were found to take place in the Lockatong and Stockton beds, so that within two or three miles of the margin the distinctions between the three subdivisions are largely obliterated.

Quartzite conglomerates.—At a number of points along the northwestern boundary of the Newark system there are thick accumulations of massive conglomerates, composed chiefly of quartzite and hard sandstone. Pebbles of limestone, gneiss and shale occur in some layers, but sparingly. All the constituent

[1] The height of the plateau above the red shale plain is not due to the fault, although the latter lies along the foot of the escarpment. As shown by Professor Davis (Proc. Bost. Soc. of Nat. Hist., Vol. XXIV, pp. 365–423) this region was base-leveled in Cretaceous times or thereabouts, and the present topography is due to differential degradation of rock masses of unequal hardness, consequent upon an uplift which affected the whole region.

materials are well rounded, a fact which in the case of the hard quartzites indicates a long period of attrition.

These conglomerates interbedded with sandstones and shales are best exposed in the "pebble bluffs" along the Delaware, above Milford. The conglomerates form lenticular beds which occasionally thin out in the distance of a few rods, to be replaced by beds of different texture. The alternation of the beds betokens shore conditions.

The heaviest accumulations of the quartzite conglomerate underlie the high region stretching northwest from Pittstown and south of Pattenburg. This region is known as "the Barrens" from the nature of the soil, an exceedingly gravelly clay resulting from the disintegration of the conglomerate. Less massive accumulations occur, also, at other points, chiefly south of Clinton, and again four miles north of Peapack, where there is an outlier of this rock called Mount Paul.

Calcareous conglomerates.—Conglomerates composed almost entirely of limestone fragments, occur at a number of localities along this border. This rock is in appearance almost the exact counterpart of the famous "Potomac marble" quarried at Point of Rocks, Maryland. The limestone pebbles are usually bluish or gray, sometimes reddish, set in a red mud matrix, so that the rock has a variegated appearance. The average diameter of the larger constituents is six or eight inches, but bowlders three feet in diameter have been seen. The larger fragments are generally rounded, but the majority of the smaller are sharp cornered, or at most subangular. Compared with the pebbles in the quartzite conglomerate, the limestone pebbles are poorly rounded, a fact of some significance in connection with the origin and source of the materials, since with equal transportation, the softer limestones must have been most worn. In many localities this conglomerate is so pure a limestone that it is quarried and burnt for lime for local use.

The relations of these conglomerates to the older rocks along the border are significant. In some localities the calcareous conglomerates adjoin small areas of Palæozoic limestone from

which the materials may have been and probably were derived. In other cases, and this is true of the largest areas, the calcareous conglomerates abut against the gneissic rocks, and for much of this distance it is certain that no limestone occurs between the gneiss and conglomerate, at least not at the surface horizon. Gneissic pebbles, however, occur but rarely in the conglomerate. Substantially the same conditions prevail in the case of the quartzite conglomerate. For the most part it adjoins the gneiss, but gneissic pebbles in it are very rare. The known areas of quartzite from which the materials could have been derived are small, and in general not near the massive conglomerate beds. These facts can be explained on the hypothesis of a fault or series of faults along the northwestern border. But on the Delaware River, at Monroe, Pa., the only locality along the border where even an approach to a good section was found, the conglomerates seem rather to overlap the older rocks at a low angle, than to be faulted against them. In view of the contradictory nature of the evidence, the question of faults along this border is still an open one.

The relation of the conglomerates to the shales is also an interesting and significant one. When traced along the strike the shales and argillites are found to grade into coarser beds which at some horizons become the massive conglomerates near the border. That this is the case has been established beyond a shadow of a doubt by numerous observations. Time and again thin pebbly layers were seen to appear in the shales and to increase in thickness and numbers until they became massive conglomerates. This is true both of the calcareous and of the quartzite conglomerates.

These conglomerates do not, therefore, form a separate horizon but range through the whole formation. Those in the bluffs on the Delaware River above Milford belong with the Brunswick shales. So also do a part of those of the Barrens southwest of Pattenburg. Those of the Barrens north and northwest of Pittstown pass into the Lockatong beds and are therefore older than the conglomerates nearer the Delaware. The pebbly

beds south of Clinton belong in the Stockton series. Both the calcareous and quartzite conglomerates near Pottersville and Peapack belong with the Brunswick beds.

It must be understood that what has been said concerning the above conglomerates does not apply to the conglomerate layers interbedded with shales and sandstones, which occur either along the southeastern part of the formation, near Hopewell or near Stockton. The latter are comparatively thin beds of little importance from a topographical standpoint, and belong to the Stockton series. They present no features of particular interest.

Thickness of the Newark sedimentary beds.—All estimates of the thickness of these sedimentary rocks contain an element of uncertainty. This arises from the monotonous character of the beds and the difficulty of detecting and measuring the faults. In addition to several very large dislocations which have been located accurately, a number of smaller fractures have been observed in quarries, railroad cuts, stream bluffs, and other exposures. Most of these could not be traced beyond the point of exposure. After making all possible allowance for known faults, I am compelled to admit that the facts in hand indicate a vastly greater thickness than has usually been supposed.

The thickness of the Stockton beds between Trenton and Wilburtha seems to be 2300 feet. No estimates can be made in the area near Hopewell, since only the upper part of the series, 650 feet or so, is there exposed. At Brookville below Stockton the base of the formation is brought to the surface by a fault and the thickness seems to be 4700 feet. No positive evidence of a fault could be found within this area to account for the greater thickness as compared with the belt near Trenton, whereas there is slight evidence that the whole series is not found near the latter place.

The thickness of the Lockatong beds is best shown on Hunterdon plateau. Here the upper and lower limits can be carefully located. The dip is more than ordinarily uniform and outcrops are sufficiently numerous to prevent any great error in

the calculation. More than this, the sweeping curve of these rocks, the uniform width of the belt, and the possibility of tracing certain subordinate but well-marked layers continuously along the strike, precludes the idea that any great part of its apparent thickness is due to repetition by faulting. Three independent measurements, made at intervals several miles apart gave results of 3540 feet, 3450 feet, and 3500 feet respectively.

Three measurements of the thickness of these same beds in the Sourland plateau gave substantially the same results, *i. e.*, 3600 feet, 3650 feet, and 3660 feet. The fact that for a part of the distance a great trap sheet has been intruded into these beds and elsewhere has caused changes in the adjoining red shales, makes it a little more difficult to measure these beds. The fact that the thickness of these beds in Sourland plateau agrees so closely with that of the same beds on Hunterdon plateau is further reason for believing that the figures here given represent very closely the actual thickness. To suppose otherwise is to assume that these two separate areas are each traversed by faults, whose throw, by a remarkable coincidence, is almost exactly the same, but no traces of which have been discovered by areal work of the most detailed character.

The thickness of the Lockatong beds of the belt near Ewingville and Princeton seems to be only about half of that in the other two regions, *i. e.*, 1700 to 1800 feet. As noted above, the same relative thinness was observed in the Stockton beds near Trenton as compared with those further north. The explanation may lie in the fact that the beds of the thinner belts are nearer the old shore line than the others. Stratified deposits have the form of an unsymmetrical lens which thins out very rapidly shoreward and very gradually seaward. It is to be expected, therefore, that the thickness of this belt would be somewhat less than that of the others, but it may be fairly questioned whether in the case of such fine deposits the difference would be so great as that indicated by the figures.

The thickness of the Brunswick beds is even more difficult

to estimate accurately. This is due to the uniformity of the red shale, which renders it very difficult to detect the presence of faults, to the folded structure, and to the fact that the entire thickness is not present in this part of the state.

West of Ringoes the shales form a syncline whose axis plunges northwest. Estimates made here show that between 7000 and 8000 feet of shales are involved in this folding. Between the mouth of Lawrence Brook, east of New Brunswick, where the shales disappear beneath the Cretaceous cover, and the base of First mountain, back of Bound Brook, the beds are 10,000 feet thick, provided there are no faults in the intervening region. In the Raritan River bluffs below New Brunswick three fault breccias were found, but nothing is known as to the amount of dislocation beyond the fact that it was not sufficient to expose the Lockatong beds which are here at a horizon about 1000 feet lower. From the amount of disturbance and crushing which is known to accompany great faults in other parts of this area, the presumption is that these are small. A deduction of 1000 feet from the above estimate would seem to be ample for these and any undiscovered fractures. Nine thousand feet, however, is not enough, since neither the base nor the top of the Brunswick beds is included in this section. They certainly extend for 2000 to 3000 feet above the base of First Mountain. In the light of the present facts an estimated thickness of 12000 feet for the Brunswick shales does not appear excessive, although in view of the uncertainties connected with the structure, too much emphasis must not be placed upon it.

The total thickness, therefore, of the sedimentary rocks of the Newark system in western New Jersey seems to be about 20,000 feet. These figures are so great that one naturally hesitates to accept them, but the facts, so far as known, do not permit any other interpretation. I began my work feeling confident that the thickness of the beds was much less than this, and that they were many times repeated by faults. However, many of the faults found cross the beds at such angles as to be ineffective in repeating the strata. Furthermore, the fact that the

three estimates of the thickness of the Lockatong beds in the Hunterdon plateau, where the outcrop is so curved, agree closely one with another, and also with the various estimates of the same beds on Sourland plateau, make it improbable that the great thickness of this series is due to faults. So, too, the thickness of a *part* of the Brunswick shales involved in a synclinal fold can be accurately determined and the possibility of the faulting there eliminated. Again a narrow trap dike was traced uninterruptedly from the back of Sourland Mountain near Rocktown to Copper Hill, a distance of five miles. The dike crosses the strike at an angle of 45° and the thickness of the shales thus traversed is between 6000 and 7000 feet. There are reasons which cannot here be specified for concluding that the Sourland trap sheet, and therefore the dike, were intruded into the shales during Newark time, and before or contemporaneous with the tilting. If these reasons are valid the continuity of the dike is proof that the shales traversed by it are not cut by faults along the strike. Since such great thicknesses prevail in these beds, which are only a part of the whole system, there is the more reason for accepting the figures given above. It can certainly be claimed for these estimates that they rest upon a much larger basis of fact than any previous figures.

Trap rock.—The trap rocks in the Newark series have been described by various writers[1] who have shown that both intrusive and extrusive sheets occur. In this connection I desire briefly to call attention to a few new facts which confirm the conclusions of some of the earlier observers.

Three narrow dikes were found to start from the upper surface of the Sourland Mountain trap mass, and were traced through the overlying shales for several miles. Their existence proves conclusively that this sheet is intrusive. It would naturally follow that the continuation of Sourland Mountain in Pennsylvania is also intrusive, although Lyman[2] has published very positive views to the contrary. Moreover the fact that the trap

[1] Chiefly COOK, RUSSELL, DAVIS, DARTON, IDDINGS.

[2] Pennsylvania State Geol. Surv., Final Rept., Vol. III, Pt. II, p. 262.

locally cuts across shales for a total of 1800 feet is certainly well established. The Rocky Hill trap sheet does not follow the strike of the shales but crosses them more or less obliquely. Where it terminates near Hopewell it is 6000 feet[1] or more above the base of the Brunswick shales, whereas at Deans station where it disappears beneath the Cretaceous beds, it is 1500 feet below them. If we are correct in assuming that Rocky Hill is a continuation of the Palisades, the sheet descends still further, since along the Hudson it is found in beds which certainly belong to the Stockton series. A recently dug quarry opposite Point Pleasant, Pa., on the Delaware, shows that the trap mass there crosses the shales at a steep angle and is also intrusive.

Near Sand Brook village, southwest of Flemington, there is a low horseshoe-shaped ridge of trap formed by the outcropping edges of a synclinal sheet whose axis plunges northwestward. This sheet is extrusive in origin, as is shown by the following facts: (*a*) It is conformable to the enclosing shale; (*b*) the upper surface is everywhere extremely vesicular and only the lower portion is dense and full grained; (*c*) the overlying shale is absolutely unaltered within one and two feet of the trap; (*d*) red shale has filled some of the cavities of the vesicular trap, and in one locality a thin layer of finely comminuted trap, glass and red shale lies between the normal red shale and the vesicular trap. This sheet has not heretofore been described or shown upon published maps.

Metamorphosed shales.—Numerous allusions are made in the earlier reports to metamorphosed or "baked" shales associated with the trap and in some cases found far away from any igneous rocks. The black argillites of the Lockatong series have been called "baked shales" by some writers and their hardness and blackness ascribed to the contact with the trap, although no igneous rocks occur near them. Metamorphosed shales do occur in connection with the larger in usive trap masses, but all the

[1] These figures are correct just so far as the above given figures of the total thickness are reliable.

hard black shales are not "baked" shales. The most marked macroscopic changes induced in the altered shales are (*a*) a greater or less induration, (*b*) change in color,—the red shales in general becoming purple and then a blue-black or green near the trap, and (*c*) the development of secondary minerals,—very commonly epidote and tourmaline. Where the change has not produced definite crystal forms or nodules, an incipient segregation has often occurred, giving the rock a more or less mottled aspect, and on weathered surfaces a warty appearance, although this latter characteristic is not limited to the metamorphosed beds, but occurs in some layers of the Lockatong beds far from any known trap.

Of these three changes the third is believed to be the most significant. Mere induration or change of color do not necessarily signify "baking," but when all three occur together and only in layers in close proximity to certain trap sheets, proved to be intrusive by their structural relations, the changes can be safely ascribed to the igneous rock. Many of the baked shales, on weathering, become a pale blue or ashy gray color, a tinge never taken by other layers.

Metamorphosed shales occur both above and below the trap of Sourland Mountain and are well exposed in the bluffs near Lambertville. They are associated also with the Rocky Hill sheet, fine exposures being found along the canal near Rocky Hill village. In fact all the intrusive trap sheets are surrounded by shales which have been more or less altered in texture, color, and mineralogical constitution. Baked shales surely exist near some of the trap sheets, but all hard, black shales of the system are not baked, as was formerly supposed.

Unclassified beds.—It has been impossible to classify definitely the beds of a small area between Mount Airy, Lambertville, and the mouth of Alexsocken Creek. Their structure is complex, the dips vary greatly in direction and amount, and in many cases they are crushed and distorted. Two small masses of trap occur within the area, and some of the beds are certainly metamorphosed. Whether they belong to the Lockatong or Bruns-

wick division I am unable to say on account of the complexity of structure and their varied lithological character.

STRUCTURE.

Folds.—The general structure is that of a faulted monocline, the beds of which trend N. 30° E., and dip 12° or 15° to the northwestward. Examined in more detail the structure is seen to depart locally from the monocline. Several broad, gentle flexures occur, in addition to a few sharply marked folds in the vicinity of the intrusive traps and greater fault lines. A good example of the former is seen in the shales of the Hunterdon plateau, where the beds are so inclined that their outcropping edges describe a great curve parallel on the east and southeast to the escarpment of the plateau. The structure is a shallow syncline, whose axis is inclined to the northwest. Low folds were found along the valley of the Raritan, particularly in the region north of Somerville. From New Brunswick to Bound Brook the dip is quite uniformly to the northwestward, averaging 10°, but to the west the monocline is interrupted by gentle flexures and swells which are difficult to trace because of the absence of individuality in the layers. The broad outcrop of the Brunswick shales in the Raritan valley is due in large part to these low folds.

More definite folds—all synclines—occur (*a*) near the Sand Brook trap sheet southwest of Flemington, (*b*) the New Germantown trap sheet, and (*c*) the Watchung traps whose great crescent curves are due to the synclinal structure of the inclosing shales.[1] In consequence of this fold the beds which outcrop near the crystallines along Mine Brook, northeast of Bedminster are at the same horizon as those between the two trap sheets back of Plainfield and Bound Brook.

Several examples of sharp folds occur near Glen Moore southwest of Hopewell and not far from the end of Rocky Hill ridge. Other instances were noted near the faults.

The beds of the Stockton and Lockatong divisions are most

[1] COOK, DARTON, DAVIS, et al.

constant in dip and strike, so that the monoclinal structure is most marked in these belts. The Brunswick shales are marked by shallow folds, some covering an area of several square miles. These combined with a fortunate arrangement of faults, have greatly increased the area of red shale outcrop, and so permitted the formation of the broad, rolling lowland, so characteristic of the greater part of the Newark system.[2]

Faults.—The location of the most important faults by which these rocks are traversed is shown on the map. The Hopewell fault, heretofore unrecognized, extends in a sinuous course from near the Delaware River by Harbourtown, Hopewell, and thence along the foot of the Sourland plateau escarpment, passing a little west of Flagtown station on the Lehigh Valley Railroad. It probably crosses into Pennsylvania, but its exact location at the Delaware River could not be definitely determined.

The evidence of faulting along this line is as follows: (*a*) the repetition of the strata; (*b*) crushed and contorted shales, slickensided surfaces or overthrown dips at every exposure along or near the fault line; (*c*) diversity of structure, dip and strike —on opposite sides of the fault line; (*d*) contrasts in topography and the termination of ridges at the fracture. The repetition of the strata has already been alluded to in describing the rocks. The map shows how the Stockton, Lockatong and Brunswick beds are repeated, the beds to the northwest having been uplifted. In the bed of every stream crossing the fault, evidence of the fracture was found in the crushed and slickensided condition of the rocks, but the fault plane was nowhere exposed. Locally the rock has been so greatly sheared as to destroy all traces of the bedding planes. Very marked overthrown dips occur in a cut just west of Flagtown station, which increase in steepness towards the fracture. Folds in the Brunswick beds on the southeast side terminate abruptly against the fault and do not affect the beds on the opposite side. The high Sourland plateau composed of the hard trap and resistant

[2] The details of structure, which must be omitted here, are given in the Annual Report of the State Geologist of New Jersey for 1896, pp. 72–78.

Lockatong argillite terminates abruptly where the fault crosses the strike of its beds. The height and prominence of the escarpment north of Skillman station is due to the contrast in hardness of the Lockatong and Brunswick shales brought into juxtaposition by the fracture.

The dislocation has been sufficient to bring to the surface the upper part of the Stockton beds, and place them side by side with the middle layers of the Brunswick shales. On the basis of the above estimates of thickness the throw cannot be less than 10,000 feet. The hade of the fault cannot be determined, since the fracture is nowhere exposed in section and its location can rarely be determined within fifty yards. North of Flagtown, where the Brunswick shales occur on both sides of the fracture, its course could not be determined.

Flemington fault.—The course of this fault previously noted by other workers[1] is best seen by reference to the map. It is located in the bluffs of the Delaware River by the juxtaposition of the coarse arkose conglomerate (Stockton) with the black argillite (Lockatong) a mile or more south of Stockton. The line of dislocation is concealed by the talus of a small ravine. From this point it extends in a northeasterly direction for three miles, thence curving a little to the north so as to pass east of Headquarters, southeast of Sand Brook and a mile west of the center of Flemington. For much of this distance it extends along the foot of the Hunterdon plateau escarpment.[2] For several miles north of Flemington its exact location becomes doubtful owing to the similarity of the adjoining beds, but one or perhaps both of the two faults along the border west of Cushetunk Mountain mark its northern extension. There is some reason for believing that the trap of Round mountain, south of Cushetunk Mountain, has ascended along the fracture, but this is not conclusively proven.

The evidence of this fault is as complete as in the case of

[1] LEWIS, DARTON, NASON, LYMAN, and others.

[2] On a "conjectural" map of the Newark formation of New Jersey (Lyman, Pa., Geol. Surv. Summary Final Report, Vol. III, Pt. II, Plate 597, also Proc. Am.

the Hopewell fault. It consists of (*a*) repetition of the strata, (*b*) diversity of structure and topography on the two sides, (*c*) local disturbances, crushed beds, overthrown dips and slickensides.

The uplift was on the northwest and was sufficient to bring to the surface the base of the Stockton beds and just across the river in Pennsylvania, the Palæozoic floor on which the Newark beds rest. East of Headquarters and Sergeantsville, lower members of the Stockton series abut against beds of the Brunswick series apparently 2600 feet above the base. If we accept the thicknesses already given, the throw of the Flemington fault near Headquarters is not less than 10,000 feet.

Half a mile east of Sand Brook village a small fault splits off from the main fracture. By it a part of the Lockatong beds of the plateau have been downthrown so that they occur to the east, and apparently below the Stockton beds. The beds between the two faults are much confused in structure.

Another and larger split fault was observed to branch from the main fracture between Headquarters and Dilt's Corners. It crosses the Delaware about midway between Stockton and Lambertville, and from a cursory examination I am inclined to believe that it joins the Flemington fault again in Pennsylvania about a mile from the river. The rocks of this block belong to the Lockatong and Stockton series with some intrusive trap masses. The general dip is south of west, although near the faults there is much diversity. The beds on the east and southeast have been downthrown relatively to the others. The combined throw of this fault and the Flemington fault is about equal to that of the latter further north.

Faults of a few feet throw have been noted in not a few cases in quarries, railroad cuts and other exposures. In still other cases the amount of dislocation could not be determined, but they could not be traced beyond the point of exposure, and the throw

Philos. Soc., Vol. XXXIII, p. 194), the fault has been located several miles from its proper position. A similar error is found on the map in Proc. Am. Philos. Soc., XXXI, No. 142.

probably was not great. It is not believed that there are other faults in the area examined whose throw is even one-tenth that of the two great ones. I have alluded elsewhere to the possibility of faults along the northwestern border. Two are shown upon the map and others are believed to exist, but are not mapped. The recurving horn of the Second Watchung Mountain is quite certainly separated from the crystallines by a fault. Further investigation of these points together with the study of the region not yet examined, is now in progress.

HENRY B. KÜMMEL.

LEWIS INSTITUTE, Chicago.

THE TOPOGRAPHY OF CALIFORNIA.

CONTENTS.

INTRODUCTION.

THE writer has recently completed a relief map of California on a scale of 1 inch to 12 miles, and a vertical scale of 1 inch to 12,000 feet. This makes it about 4 by 5 feet square, and the highest peaks nearly 1¼ inches high.

The accompanying plate was taken from a photograph of this map, and illustrates the main topographic features of the state. To give some idea of the accuracy of the topography as shown, the method of making the map is given.

Method of making the relief map.—As no topographic map of the state was available, all the maps, levels, and other topographic data were collected and a contour map of the state compiled.

The topographic data were obtained principally from maps of the State Mining Bureau,[1] the United States Geological Survey, the United States Coast and Geodetic Survey, various reconnaissance surveys, and from topographic descriptions and railway surveys, and from elevations of peaks, passes, and places obtained from various sources, both published and unpublished.

The gross relief of the state was then built up on a rigid wooden base by cutting out card-boards of the proper thickness in the shape of each 1000-foot contour and nailing them in place one on top of the other. The steps or terraces made by the card-board and the minor details of relief were then filled in with wax.[2] The best reference maps of the particular area being modeled, were kept constantly at hand during the process of filling in the details. After the completion of the original, a negative was made in plaster of Paris, and from this the positives are made. The completed relief map represents about six months of continuous and careful work. It shows the relief with all the detail which the scale permits except in those parts of the state in which topographic data are wanting. But even in these parts the drainage made it possible to show the general features fairly well.

TOPOGRAPHIC REGIONS.

General features.—The northern part of the state is largely composed of three parallel and almost equally extensive topographic belts running lengthwise the state. These belts are the Sierra Nevada on the east, the California Valley in the center, and the Coast Ranges on the west. The Sierra Nevada, with its main crest from 6000 to 13,000 feet above tide and its highest peak reaching an elevation of nearly 15,000 feet, is the highest and most prominent mountain system of the state. The continuation of the Sierra Nevada in extreme northern California is

[1] The Preliminary Mineralogical and Geological Map of California, issued in 1891 by the State Mining Bureau, was used as a base.

[2] This wax was composed of 16 parts of beeswax, 8 of cornstarch, 4 of Venice turpentine, 1 of Venetian red, and 1 of sweet oil.

called the Cascade and the Lava Sheet mountains. The mountains next in importance to the Sierra Nevada are the Coast Ranges, which have an average elevation of about 4000 feet, a

width of 50 to 100 miles, and with the exception of a break at San Francisco Bay, extend along the coast for the full length of the state. The Coast Ranges, however, are more or less broken at a number of places, thus giving rise to rather distinct groups of mountains which have received special names. The southern

end of the Sierra Nevada makes a sharp curve to the west, meeting and uniting at Téjon Pass with an eastward curving branch of the Coast Ranges.

The Klamath Mountains, occupying the northwestern part of the state, unite the Coast Ranges and the Cascade Mountains. Between these mountain ranges lies the California Valley, which extends nearly northwest and southeast, and is about 400 miles long by 50 miles wide. It is drained by the Sacramento and San Joaquin rivers.

The southern part of the state has three distinct topographic areas, one of which lies along or near the coast, and is the continuation of the Coast Ranges under the name of the Sierra Madre Mountains. This mountain system is composed of several different ranges, the principal ones being the San Gabriel, the San Bernardino, and the San Jacinto. The breaks between these mountain ranges are not complete, so the system is prolonged by successive ranges to and beyond the southern boundary of California.

Another of these topographic districts is the northern part of southeastern California; this is composed of narrow and parallel mountains and valleys running north and south. The mountains are high, and the valleys narrow and closed. Farther to the south the relief is composed of irregularly grouped and rather low mountains, flat intervening table-lands and closed drainage basins.

The Sierra Nevada.—The Sierra Nevada is essentially a single mountain chain with a summit line deviating but little from the general trend of the mountains. This summit line is near the eastern edge of the range, except in the extreme northern part where it extends nearer to the western limit of the mountains. The eastern slope of the mountains is especially abrupt. The fall from Mt. Whitney to Owen's Valley, a distance of ten miles, is about 10,000 feet.[1] The western slope approximates a long, broad, inclined plain, furrowed deeply and closely by numerous canyons. By observing the accompanying plate it may be seen

[1] J. D. Whitney, Geological Survey of California, Vol. I, p. 456.

that if these canyons were filled level to the tops of the ridges the result would be an irregular, slightly warped, tilted plain. In general the grade of this tilted plain is quite regular from the low elevation of the California Valley to the top of the mountains. This western slope was probably once a region worn down almost to base level or to a peneplain. By the uplift of the mountains a great fault was developed along the eastern face and the whole Sierra crust-block tilted to the westward. The streams quickened by the uplift again set to work on the peneplain and carved it to its present condition. According to Professor Joseph Le Conte:[1]

The Sierra was formed, as we now know, by lateral crushing and strata-folding at the end of the Jurassic. But during the long ages of the Cretaceous and Tertiary this range was cut down to very moderate height. . . . . The rivers by long work had finally reached their base-levels and rested. The scenery had assumed all the features of an old topography, with its gently flowing curves. . . . . At the end of the Tertiary came the great lava streams running down the river channels and displacing the rivers; the heaving up of the Sierra crust-block on its eastern side, forming the great fault-cliff there and transferring the crest to the extreme eastern margin; the great increase of the western slope and the consequent rejuvenescence of the vital energy of the rivers; the consequent down-cutting of these to form the present deep canyons and the resulting wild, almost savage, scenery of these mountains.

J. S. Diller's researches in the northern part of the Sierra Nevada further strengthen these theories, as the following quotations from him will show:

A study of the ancient topographic features upon the borders of the Sacramento valley, in the Klamath Mountains, and upon the western slope of the Sierra Nevada, shows that during the earlier portion of the auriferous gravel period northern California, by long-continued degradation, was finally reduced approximately to base-level conditions. The mountain ranges were low, and the scenery was everywhere characterized by gently flowing slopes. . . . . The topographic revolution consisted in the development out of such conditions of the conspicuous mountain ranges of today. The northern end of the Sierra Nevada has since been raised at least 4000 feet, and possibly as much as 7000 feet, and a fault of over 3000 feet developed along the eastern

[1] Bull. Geol. Soc. Am., Vol. II, pp. 327–328.

face of that portion of the range. . . . . The amount of uplift decreases rapidly towards the Sacramento valley.[1]

Mr. Waldemar Lindgren thinks the Sierra Nevada was eroded to, or almost to, a peneplain during Cretaceous times, and that the mountains elevated in a later Cretaceous period were worn down during Tertiary times merely to a gentle topography.[2]

Of the origin of the range he says:

At this time[3] . . . . the first break took place, separating the Sierra Nevada from the interior basin. The orogenic disturbance was probably of a twofold character. It included the tilting up of the whole region between the Wasatch and the Pacific in arching form, and a simultaneous breaking in and settling down of the higher portions of the arch. Thus the Sierra Nevada crust fragment was formed, the larger part of which has ever since remained a comparatively rigid block. Along the eastern margin the system of fractures was outlined which toward the close of the Tertiary was to be still further emphasized.

The evidences that the Sierra Nevada is a tilted and eroded peneplain with a fault line along its eastern edge may be summed up as follows:

(1) The present features of the western slope of the mountains resemble a tilted and dissected peneplain. The precipitous slope on the eastern side marks the fault line.

(2) Fossil plants,[4] which indicate a low altitude at the time of the deposition, have been found in the auriferous gravels in the northern part of the Sierra Nevada.

(3) The auriferous gravels now found in the old river beds along the western slope of the Sierra Nevada must have been deposited in streams flowing down gentle grades.

(4) Many of the old river valleys are terraced, showing successive stages of elevation as well as low stream grades.[5]

(5) The present rivers flow directly across the upturned edges

[1] 14th Ann. Rept. U. S. Geol. Surv., Part II, p. 433.

[2] Jour. Geol., Vol. IV, pp. 882, 894, 897, and 898.

[3] Jour. Geol., Vol. IV, p. 894.

[4] J. S. Diller, 14th Ann. Rept. U. S. Geol. Surv., pp. 421–422.

[5] J. S. Diller, 8th Ann. Rept. U. S. Geol. Surv., Part I, p. 429.

of Mesozoic and Palæozoic beds on the lower slopes of the mountains.

(6) The Tertiary lavas on the western slope of the Sierras cover a gentle topography.[1]

It has been noted that the Sierra Nevada is now deeply carved by the streams flowing down its western slope. The canyons vary in depth from a few hundred to six thousand feet; their walls are very steep, and in places perpendicular; in the Yosemite and King's River canyons there are perpendicular walls over three thousand feet high.[2] These canyons run approximately at right angles to the trend of the mountains and parallel with each other. This direction and parallelism is especially true of the larger canyons, which form a series quite regularly spaced throughout the length of the mountains.

The parallelism of the canyons is due principally to the two causes of uniform direction of tilting and the parallel system of fault and fissure lines. It is generally conceded that the great canyons, as well as many smaller ones, run along fault lines.[3]

And it has been observed[4] that often the canyon following one system of fissures crosses over to another system and follows it. G. F. Becker has pointed out that in places these fissure lines are so close together as to amount to shattered zones, and that the main fissure systems cross at right angles.[5]

So a probable explanation for such places as King's River and Yosemite Valleys is that they are the locations of shattered zones removed by erosion, so that the fissures bounding the shattered zone now form the faces of the perpendicular exposed valley or canyon walls.

It may be seen from the accompanying plate that the canyons west of Lake Tahoe, especially North Yuba River, Middle

[1] WALDEMAR LINDGREN, JOUR. GEOL., Vol. IV, p. 897.

[2] J. D. WHITNEY, Geol. Surv. Calif., Vol. I, pp. 410 and 421. JOHN MUIR, Century Magazine, Vol. XVIII, p. 488, and Vol. XXI, p. 80.

[3] G. F. BECKER, Bull. Geol. Soc. Am., Vol. II, p. 68. The Rocks of the Sierra Nevada, by H. W. TURNER, 14th Ann. Rept. U. S. Geol. Surv., p. 443.

[4] G. F. BECKER, Bull. Geol. Soc. Am., Vol. II, p. 68.

[5] Bull. Geol. Soc. Am., Vol. II, pp. 50–51 and 68.

Yuba River, Bear River, North Fork and Middle Fork of American River, receive almost all their drainage from the north side, which would seem to indicate that each of these main canyons followed a fault line, and that in addition to the westward tilting of the mountain mass these separate smaller blocks between the canyons tilted to the southward also.

The regularity of the canyon system and the westward-sloping, eroded plain is somewhat more broken to the south of Merced River, where the principal rivers, *i. e.*, the San Joaquin, the Kings, the Kaweah, and the Kern, have a wide range of tributary streams and have carved out more basin-like drainage areas. It appears that the southern end of the Sierras has existed longer as a mountain range; and also that the Tertiary lava flows that spread over northeastern California as far south as Merced River did not bury the drainage systems farther to the south. Thus it seems that these drainage systems are older and naturally more basin-like or collected in larger groups.

The Kern River is the first to break the general westward course and flow south for most of its length before turning towards the California Valley. The parallelism in the tributaries of the upper course of the Kern forcibly suggests faulting and folding along parallel north and south lines, and probably southward tilting also, to guide the streams.

Cascade region.—The northeast part of California is a table-land with cone-shaped peaks here and there rising above the general level. Toward the east the flat table-lands are broken by ridges extending north and south which usually have a steep slope on the east side and a gentle slope on the west side. The lava outflows that spread over southeastern Oregon extend in a sheet over this area forming the table-land. The cone-shaped peaks are lava outpourings, where the lava flows were concentrated at points. Mt. Shasta and Lassen peaks are notable examples of volcanic cones on the western side of this area. In the northeast corner of this area fault lines are prolonged southward from a fault system extended down from southeastern

Oregon.[1] Small orographic blocks between these fault lines are usually tilted westward and form ridges and basins such as Warner Mountains, Alkali Lakes basin, and Goose Lake basin.

Klamath Mountains.—To the west of the lava sheet lies the irregular group of mountains known as the Klamath Mountains.

This region has long been subjected to erosion, and to oscillations[2] from archipelago to high land elevations. The outpouring of lava and accumulations of sedimentary beds on the flanks of the granitic core and the irregular tilting, and faulting, have produced a complex mountain mass and an area of tortuous stream courses.

The Coast Ranges.—Joining the Klamath Mountains on the southwest, and extending southward along the coast are the Coast Ranges. The typical part of this system lies west of the California Valley. This part of the Coast Ranges is composed of numerous parallel ranges, ridges, valleys, and canyons which extend in almost straight lines along and parallel with the coast. The elevations of opposite ranges are usually approximately the same. At places the opposite ranges are completely separated, but usually they coalesce, only to break again along the same lines. Thus along any given line through and parallel with the ranges, a topographic feature may disappear but it occurs again after a short break. These parallel lines of topographic features show the close kinship of the ranges and extensive fault lines and folding axes.

[1] J. C. RUSSELL, A Geological Reconnaissance in Southern Oregon. 4th Ann. Rept. U. S. Geol. Surv., pp. 436–464.

[2] "At the close of the Taylorville Jurassic there was an upheaval by which the Klamath Mountains were outlined."—J. S. DILLER, Bull. Soc. Am., Vol. IV, p. 224.

"During the Cretaceous period, especially during that portion represented by the Shasta-Chico beds, northern California gradually subsided. . . . . The Klamath Mountains during a part of this time, at least, formed an island."—J. S. DILLER, Tertiary Revolution in the Topography of the Pacific Coast. 14th Ann. Rept. U. S. Geol. Surv. 1892–3, pp. 23–24.

"During Miocene times . . . . the Klamath Mountains were low with gentle slopes as compared with those of the present ranges; and the streams flowed down their flanks in broad shallow valleys instead of in deep canyons as they do now."—JOUR. GEOL., Vol. II, p. 44; also 14th Ann. Rept. U. S. Geol Surv., p. 423.

Lawson has shown[1] that a considerable part of this region has been eroded to base level and when this area was elevated to a plateau, erosion followed the weak lines, dissecting the plateau until only the tops of ridges are now left as evidence of the once leveled region. The larger ranges and valleys, however, appear to be of orogenic rather than erosive origin. Local shifting of land elevations or the irregular tilting of some small blocks of the earth's crust has divided some of the larger valleys such as Russian River—Petaluma Valley, and the Santa Clara-San Benito Valley. In both cases the adjoining valleys are continuous, but from tilting of earth-crust blocks the valleys are slightly divided so that their drainage runs into the ocean or bays at different places. An elevation of the southern end of the Santa Clara Valley has turned the San Benito River to one side so that it now flows through a narrow outlet into the Bay of Monterey instead of continuing in the straight and open valley to the north and emptying into San Francisco Bay. Similarly the southward continuation of the Russian River Valley leading into San Pablo Bay is so tilted as to throw the Russian River drainage to one side through a narrow outlet into the ocean. Such local tilting of the earth's crust causing the flooding of valleys is the origin of San Francisco Bay, Tomales Bay,[2] and probably[3] Monterey Bay. This shifting has been so late that the effects of subsidence are plainly shown in adjoining valleys. Tomales Bay[4] is clearly one of these drowned valleys. It is a long riverlike bay that is about three-quarters of a mile in width and fifteen miles long. The valley of the bay continues to the southward until it reaches the ocean again.

The great valley of California.—The California Valley, lying between the described mountain systems, is a low, level area about 400 miles long and 50 miles wide. The width of the valley is quite regular throughout, but is somewhat greater at the southern end and a little north of the center. At this latter

[1] Bull. Dept. Geol. Univ. Calif., Vol. I, No. 8, pp. 242–244.

[2] A. C. LAWSON, Bull. Dept. Geol. Univ. Calif., Vol. I, pp. 263–269.

[3] A. C. LAWSON, Bull. Dept. Geol. Univ. Calif., Vol. I, p. 59.

[4] A. C. LAWSON, Bull. Dept. Geol. Univ. Calif., Vol. I, No. 8, p. 264.

place the San Joaquin and Sacramento rivers, which are the principal streams of the valley, are confluent and flow westward through the straits of Carquinez, thence through San Francisco Bay into the ocean. Well borings at different places over the valley show the upper 1000 feet or more of the valley deposits to be fluviatile and subaërial,[1] for the strata consists of alternating beds of sand, clay, and gravel, and in places contain loess-like[2] strata and organic remains[3] of land and fresh water animals.

The origin and growth of the valley, as stated by F. L. Ransome, is in brief as follows:[4]

> With the post-Pliocene elevation of the crest of the Sierra and with the gradual upward diastrophic movement of the Coast Ranges during Pleistocene times . . . . the valley became closed in by mountains as we find it at the present day . . . . .
>
> All through Pleistocene and recent times, the streams flowing down from the Sierra, and from the eastern slope of the coast ranges have been pouring detritus into the deepening valley, depositing the coarser materials in broad alluvial fans and carrying the finer silt farther out to be spread over the plain in flood seasons.

So it seems that this area has been largely built up at equal pace with its subsidence, usually existing as a low, marshy tract, retaining a large part of the detritus brought down from the Sierras and Coast Ranges. The southern end of the valley is a low, marshy area, with no well-defined outlet, and at the present time retains all the detritus and sediment brought there from the adjoining mountains.

The Sierra Madre Mountains.—It has been noted that west of the California Valley the axes of the coast ranges run nearly northwest and southeast, but the further continuation of the coast ranges to the southward is first marked by almost east and west axes, which are in turn followed by ranges running northwest and southeast. In each case the coast line turns and runs parallel with the axes of the mountains along the coast. The

[1] Eighth Ann. Report Calif. State Mineralogist, 1888, pp. 558–560; Tenth Report, 1890, pp. 548–564; Twelfth Report, 1893, pp. 350–351.

[2] Bull. No. 3, Calif. State Mining Bureau, p. 16.

[3] Bull. No. 3, Calif. State Mining Bureau, pp. 20 and 68.

[4] The Great Valley of Calif., Bull. Dept. Geol. Univ. Calif., Vol. I, p. 398.

islands off the coast of southern California have their longer axes lying in the same direction as the opposite shore line and mountain range, showing that these islands belong to the system of orogenic movements that created the mountain ranges of the mainland and are remnants of partly submerged mountain ranges.

The parallel grouping of mountain chains, which is so prominent a feature of the Coast Ranges to the north, is much less marked in the Sierra Madre Mountains, where the mountain system consists essentially of successive single ranges, somewhat elongated in the axial direction, but consisting of a central mass, from which spurs radiate in all directions.

Owens River—Death Valley district.—This topographic region is the southern end of the Great Basin mountain system. The mountains and valleys of this system are parallel and run north and south. The mountains are usually high, and the valleys low and narrow. This topography is one of block faulting, which gives the great extremes in elevation and the narrow straight lines of mountain ranges and valleys. Drainage is now poorly defined, because the rainfall is so light that no permanent streams of any considerable length exist. Nearly every valley is a closed basin that has been filled to a considerable depth with detritus from the adjoining mountains. Death Valley, though having this usual filling of detritus, is, at its lowest place, 480 feet[1] below sea level.

Mohave—Colorado River district.—Southeastern California has rather low, irregular-shaped mountains, flat table-lands, and low, closed drainage basins. Nearly all the mountains and hills have the appearance of being partially buried, so that only their tops project, island-like, above the surrounding plains. In this region there is but little or no drainage to carry off the disintegrated rocks. The débris, blown and drifted around, fills the valleys until only the tops of the hills project above the débris-covered plain. This area is a meeting point for several mountain systems, and therefore has a mixed arrangement of its mountains.

[1] North American Fauna, No. 7, Death Valley Expedition, Part II, p. 367.

MINOR TOPOGRAPHIC FEATURES.

Besides the general topographic features which may be seen from the accompanying plate, there are others too small to show, but nevertheless of considerable importance.

Terraces.—There are, along almost the whole length of the coast, benches and rounding bluffs of more or less prominence. Some of these terraces are only seen after close observation, while others form benches of considerable width.

As shown by Lawson,[1] these are marks of old seashores, and show successive elevations of the land through Quarternary times.

Mesas and table-lands.—These are marked features of the coastal plain north of San Diego, and occur on the sides of river valleys farther to the north. This characteristic feature may be observed in the Salinas Valley at King City. Lawson has shown[2] that the Pliocene corresponds to a time of general subsidence of the coast, when the sea encroached upon the land, flooding the low coast lands and valleys. These flooded coast margins and valleys thus became the dumping ground for the sediment from neighboring lands until the accumulations grew to great thickness. Then, when the land rose and erosion carved this accumulated sediment, mesas and table-lands were left.

Alluvial cones and fans.—In parts of the state where the rainfall is light or not sufficient to carry the disintegrated rocks any considerable distance it is common to see along the valleys, at the mouths of mountain canyons, the valley built up higher, so that the mouth of the canyon is buried beneath a cone of débris. The writer has observed this in the White Mountains near the California-Nevada state line, where, standing at a commanding place some five or six miles from the mouth of a large canyon, it seemed as if all the débris removed to cut out the canyon had been distributed at the mouth of the canyon and extended in

[1] Bull. Dept. Geol. Univ. Calif., Vol. I, Nos. 1, 4 and 8.

[2] The Geology of Carmelo Bay, Bull. Dept. Geol. Univ. Cal., Vol. I, No. 1.

The Post-Pliocene diastrophism of the Southern Coast of Calif., Bull. Dept. Geol. Univ. Cal., Vol. I, No. 8.

decreasing amount for two or three miles into the valley and to the right and to the left along the mountain side. This feature is beautifully shown on some of the United States Geological Survey topographic sheets[1] of southern California, where at the mouths of large canyons, such as the San Gabriel, instead of the contours running up towards the canyon, they circle around or away from it. Where the rainfall is somewhat greater the débris is carried further and distributed over a wider area, forming a fanlike extension of sediments. This feature has already been referred to in the discussion of the California Valley.

Superimposed drainage.—Near the head of Salinas Valley or immediately south of Santa Margarita, there is a valley from one to two miles wide underlaid by rather soft Tertiary sandstones and shales. To the east of the valley there is a granitic mountain range nearly 2000 feet high, while to the west there is a parallel range about 3000 feet high which is composed of rather soft Tertiary shales and sandstones. The Salinas River, instead of running through this valley, runs close by and parallel to it through a narrow deep canyon in the granitic mountain range. One stream in particular, and others to some degree, that run down from the western or sedimentary range of mountains, follow the valley for a few miles and then cut through the granitic hills by narrow canyons and flow into the Salinas River. The divides in the valley deflecting the streams are only about 100 feet[2] above the bed of the river while the narrow strip of granitic hills cut off between the river and valley, rises six and seven hundred feet above the river bed.

It seems most probable that in this case the soft sandstone and shales originally extended over the granitic mountains, as well as the valley and mountains to the west, and that the river was originally situated vertically over its present course, so that it has carved its way down through the soft covering and thence into the granite, and has so far kept below the more recent erosion-valley in the soft beds by its side.

[1] The Cucomonga and San Bernardino sheets of the U. S. Geol. Survey.

[2] See San Luis Obispo sheet U. S. Geol. surv. maps, surveyed in 1895.

EFFECTS OF VEGETATION ON TOPOGRAPHY.

Sand dunes.—During the summer of 1895 the writer assisted in mapping a number of sand dune areas along the coast in San Luis Obispo county. In all these areas there seemed to be no exception to the rule that where the sand was free from vegetation or obstruction, it was piled in ridges at right angles to the prevailing sea breezes, and that where patches of vegetation grew the dunes became parallel to the direction of the wind, and where the vegetation became thicker over the ground, the regularity of arrangement of the dunes was more broken. It seems that the change in direction of the dune ridges (from right angles to parallel with the winds where vegetation began), is due to the fact that vegetation once started would check the sand from moving at that point and make a shelter for deposits to the leeward. This point of the sand dune now being more stable, other plant growth would spring up, mainly on the leeward side, so as to lengthen and increase the elevation of the ridge while the unprotected sands at either side would drift away, thus forming narrow parallel ridges in the direction of the prevailing winds. Ridges fifty to seventy-five feet high and 400 to 600 feet long, or even longer, were not uncommon where the sand dunes are extensive.

Hill slopes.—While mapping over the area south of San Luis Obispo for some twenty or twenty-five miles, it was observed that the slope of the north side of the hills was steep while that of the south side was gentle. This proved to be almost invariably true, no matter in what direction the strata dipped or whether the underlying rock was loose sand.

This part of California, like most of the state, has a dry season and a wet one. During late spring, all summer, and early fall there is no rain and therefore any shelter from the sun's heat insures thicker and more permanent growth. So the north sides of the hills are more thickly covered with vegetation, especially perennial growths, and timber is often completely confined to them. The roots, leaves, and débris of the vegetation would protect the soil from washing away, while on the

south side of the hills the almost barren ground would lose much of its soil at every freshet. Over most of this area erosion is lowering the hill tops about as fast as stream corrasion lowers the creek beds. So the vertical distance between hill top and stream bed remains nearly the same, while the horizontal distance on the north side of the hill becomes less because the hill top recedes to the north as its south side is the principal one to be trimmed back by erosion. Such a process would in time almost produce a bluff. Such steep hill-sides may be seen immediately east of Arroyo Grande along the south side of Tar Springs Creek, San Luis Obispo county.

Topography as modified by rainfall.—In southeastern California where it is especially arid, there is almost no vegetation to hold the soil and disintegrated rock in place, so the weathered, loose, rock-fragments are soon blown to low ground leaving the rocks of the hillsides exposed in rough angular forms and the topographic outlines strongly fixed by the character of the rock mass or strata.

In the humid portion of the state, however, vegetation holds the soil from washing or drifting away and as the rocks continue to disintegrate, the hills are covered and rounded off by this mantle of soil and débris. Besides this reason for the rolling character of the topography, the following causes may be added: The sedimentary rocks as a rule are soft and much broken by numerous fissures, faults, and folds, so hard and fast lines or horizons to resist weathering do not often exist. The igneous rocks are usually great masses and necessarily show their characteristic rolling topography.

Taken as whole probably the most characteristic feature of the topography of the Pacific Coast is the rolling nature almost everywhere seen where relief is shown. This feature is especially impressive to one familiar with the bench, bluff, and flat topped mountain topography of the Mississippi valley region.

Noah Fields Drake.

Stanford University,
California.

A COMPARATIVE STUDY OF THE LOWER CRETACEOUS FORMATIONS AND FAUNAS OF THE UNITED STATES.[1]

INTRODUCTION.

BESIDES the facts of wide distribution and economic importance the Cretaceous is notable for the problems of more purely scientific nature than it presents. For example, near the middle of Cretaceous time or at the beginning of the neo-Cretaceous (to adopt William's term) there was a great transgression of the sea upon the land—perhaps the greatest and certainly one of the most clearly recorded extensive one in geologic history. During the Trias and Jura almost all the present area of the continent was above sea level, as is shown by the absence of marine strata of those periods, excepting in limited areas of the Rocky Mountain and Sierra Nevada regions. The advance of the sea commenced with the Cretaceous, covering nearly all of Mexico and extending northward in the United States to southern Kansas, besides encroaching on the coast range region in the West while the lower Cretaceous sediments were forming. Then there was a greater and more rapid advance until at its maximum extent the sea covered almost the entire area between the Mississippi River and the Wasatch range, extending northward to the Arctic Circle. It also washed the western slope of the Sierra Nevada and covered the entire coastal plain of the Atlantic and the Gulf. The advance was not continuous nor constant, however. There were retrograde movements so that locally fresh-water and brackish-water deposits with associated coal beds are interstratified with the marine formations. Before the close of the Cretaceous while the Laramie beds were being

[1] Thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Columbian University, Washington, D. C., June 1897.

laid down the sea had retreated from most of the continental area and it has never since invaded it beyond the coastal border regions. It is a noteworthy fact, as Neumayr[1] and others have pointed out, that there was a similar invasion of the sea upon the other continents in mid-Cretaceous time.

The occurrence of contemporary marine, fresh-water and brackish-water formations has greatly complicated the classification and correlation of the Cretaceous beds. Deposits formed under such diverse conditions naturally have few features in common, either lithologically or paleontologically, and their correlation must usually depend on similarity of stratigraphic and structural relations with formations of known age. In a few cases, however, the same flora and other land organisms have been preserved in both marine and fresh-water beds, and have thus demonstrated their practical contemporaneity.

Besides the sharp contrasts between marine and non-marine beds there are several distinct facies within the marine Cretaceous formations. Whether the paleontological differences are due to climate, to isolation, to differences in depth or in the nature of the sea bottom, are questions that should be solved independently in each case, but their solution is usually difficult. The first essential is to determine that the formations compared are actually contemporaneous or homotaxial. A failure to do this has led to serious errors in the past. For example, Roemer[2] noticed that the Cretaceous fauna of New Jersey is very different from that found in Texas in beds that he supposed to be contemporaneous. He also noticed that the former corresponded rather closely with the Cretaceous fauna of northwestern Germany, while the Texan fauna found its nearest analogues in the Cretaceous of southern Europe bordering on the Mediterranean. He concluded, therefore, from these geographic relations that the faunal differences were due mainly to climate, that the present climatal zones were already established in Cretaceous time and even that the ocean currents had

[1] Erdgeschichte, Bd. 2, p. 377.

[2] Am. Jour., Sci. 2d. ser., Vol. II, 1846, p. 364. Kreideb. v. Texas, 1852, p. 25.

approximately their present positions, since the European localities are respectively several degrees farther north than their American analogues, corresponding to the position of isothermal lines on opposite sides of the Atlantic at the present time. This was one of the first attempts to establish climatal zones at such an early period, as it was published even before von Buch's[1] generalization that the absence of Cretaceous faunas in the polar regions is due to the climatic conditions of that period. In Neumayr's studies of Mesozoic climates use was made of the difference between the Cretaceous faunas of New Jersey and Texas, and it has recently been cited by Kayser[2] and by J. Perrin Smith.[3] There is some evidence of the existence of climatal zones in the Cretaceous and even earlier in Mesozoic time, but Roemer's original examples should no longer be cited as proof, for it is now known that the faunas Roemer compared were not contemporaneous, the base of the marine Cretaceous beds in New Jersey being somewhat newer than the uppermost horizon that furnished the fossils he described from Texas. If he had made his comparisons with the Ripley fauna, which occurs near the top of the Texan Cretaceous and only a few miles east of the beds studied by him, Roemer's conclusion would probably have been very different, for a very large percentage of the species are identical with the New Jersey forms, and there is nothing suggestive of a warmer climate.[4] The Upper Cretaceous faunas of the Atlantic and Gulf border regions, when comparison is made with strictly homotaxial zones, are remarkably uniform along the whole coast from Texas to New Jersey.

The correlated faunas of the Rocky Mountain region and the great Plains show much greater differences when compared with the faunas just mentioned, and these may reasonably be

[1] Verbreitung und Grenzen d. Kreidebildungen. Verhandl. des Naturhist. Vereins d. Preuss. Rheinlande u. Westphalien, Bd. 7, pp. 211–242.

[2] Text-book of Comparative Geology, translated by Lake, p. 283, Lond., 1893.

[3] Jour. of Geol., Vol. III, p. 485, Chicago, 1895.

[4] See Whitfield; Bull. Am. Mus. Nat. Hist., Vol. II, 1889, pp. 113–116 and White, Bull. U. S. Geol. Surv., No. 82, pp. 84, 111.

attributed in part to the influence of climate, but it would carry us too far from our subject to discuss this question fully.

The life of the Cretaceous period offers many other points of general interest, chief among which is the fact that while it is essentially Mesozoic in character, and is thus allied with the life of earlier periods, it nevertheless includes the earliest recorded repres ntatives of very many recent generic and family types and some groups of higher rank, and in the later stages this modern element is often relatively large. This statement refers chiefly to plants and invertebrates, for, with the exception of the Teleost fishes, which are introduced for the first time, the vertebrates nearly all belong to types now extinct or of relatively little importance. So far as the record goes the great group of placental mammals was not yet introduced, and the vertebrate fauna consists largely of Mesozoic types of reptiles, such as dinosaurs, pterosaurs and pythonomorphs, with a few small mammals of the lowest groups, and birds of archaic types.

Among the invertebrates the Ammonoidea are very greatly differentiated and finally become extinct with the close of the period. Many other forms, such as Inoceramus, certain types of Ostreidae, Nerinea, Anchura, Pugnellus, etc., do not pass the upper limits of the Cretaceous. On the other hand, the Ostreidae, Anomiidae, Mytilidae, Unionidae, Veneridae, Mactridae, Turritellidae, Naticidae, Volutidae, etc., are represented by forms closely related to living species. The flora is completely revolutionized and modernized during the Cretaceous. Early in the Cretaceous the first Dicotyledons occur and by mid-Cretaceous time they largely predominate and numerous genera of trees that time still live in our forests are already introduced, so that the biologist who is studying recent species must often go back to the Cretaceous faunas and floras to complete his data for a rational classification.

RECOGNITION OF THE LOWER CRETACEOUS IN THE UNITED STATES.

Before going farther it may be well to recall the general classification of Cretaceous deposits as adopted in Europe. It is

now customary to recognize only two principal divisions — Lower Cretaceous and Upper Cretaceous — instead of three as formerly. The number and nomenclature of the subdivisions varies in different countries and with different authors, but the terms Neocomian, Urgonian, Aptian, Albian, Cenomanian, Turonian, Senonian and Danian proposed by d'Orbigny are frequently used and universally understood.

In Neumayr's *Erdgeschichte*[1] the following arrangement is adopted:

Upper Cretaceous.	Lower Cretaceous.
Senonian.	Gault.
Turonian.	Aptian.
Cenomanian.	Neocomian.

In this classification of the Lower Cretaceous the Wealden is treated as simply a non-marine facies of the Neocomian, the Urgonian is made a subdivision of the Neocomian (as it was by d'Orbigny also) and the English name Gault is substituted for Albian. Some authors place the Gault in the Upper Cretaceous, but for comparison with American formations it is more satisfactory to classify it with the older beds.

These minor subdivisions are not applicable to the American Cretaceous excepting in the most general way, and, as Dr. White has insisted, it is not probable even that the corresponding principal divisions as recognized on the two continents are strictly homotaxial, but the accumulating evidence tends to show that the difference is not very great. In making an independent and natural classification of our formations we have perhaps placed a few beds in the Lower Cretaceous that by European standards would go in the Upper Cretaceous.

The first definite recognition of Lower Cretaceous in this country based on good evidence was by Professor Jules Marcou,[2] who in 1855 identified a number of fossils from Texas as Neocomian, and asserted that rocks of that age cover considerable

[1] Bd. 2, p. 344.

[2] Pacific R. R. Reports, 8vo edition, Vol. IV, pp. 40–48, 1855; republished in 4to edition and in Geology of North America.

areas in Texas and Indian territory. Marcou has maintained the correctness of his determination in numerous subsequent papers, but for various reasons his opinion, though essentially correct, did not meet with general acceptance for many years. The principal causes that conspired to prolong this misconception were (1) Marcou's own error in referring to the Jurassic certain New Mexican exposures of a part of the same series; (2) Roemer's previously published important work, "Die Kriedebildungen von Texas," in which on paleontological grounds all the Texan Cretaceous beds were referred to the Upper Cretaceous;[1] (3) the publication of Shumard's[2] section in which the stratigraphic succession is very erroneously given, and (4) the fact that the investigation of other regions in the United States did not reveal any Lower Cretaceous beds that were really comparable with those of Texas. The subject remained thus until 1887 when the publication of papers by Dr. C. A. White[3] and Mr. R. T. Hill,[4] based on the latter's field work, established the fact that there is in Texas a great series of Cretaceous rocks underlying the generally recognized Upper Cretaceous of other parts of the country. This is the Comanche series that has since become so familiar through the numerous papers of Mr. Hill.

[1] The idea has been current for some years that ROEMER's principal error was a stratigraphic one in placing his "Cretaceous of the Highlands" above the "Cretaceous at the foot of the Highlands" as he did tentatively in his earlier work "Texas," but a careful perusal of the introductory pages — especially page 19 — of the "Kreibildungen" will show that he did not finally attempt to establish any stratigraphic succession, and that he admitted that there were both paleontologic and physical reasons for regarding the beds of the Highlands as older than the others, and he suggested that their topographically higher position might have been caused by a fault. His real error was that in his paleontological comparisons with the Cretaceous of southern Europe, he did not recognize the now well-known fact that there are two distinct horizons, one in the Upper Cretaceous and the other in the Lower, each characterized by peculiar species of Rudistae, Chamidae, etc.

[2] Trans. Acad. Sci., St. Louis, Vol. I, pp. 582–589, 1856–1860.

[3] On the Cretaceous formations of Texas and their relations to those of other parts of North America. Proc. Phila. Acad. Nat. Sci., 1887, pp. 39–47.

[4] The topography and geology of the Cross Timbers and surrounding regions in northern Texas. Am. Jour. Sci., 3d ser., Vol. XXXIII, pp. 291–303, pl. 6. The Texas section of the American Cretaceous. Am. Jour. Sci., 3d ser., Vol. XXXIV, 1887, pp. 287–319.

Some years before the investigation of the Texan Cretaceous was begun several geologists described strata in Virginia, Maryland, Delaware, and New Jersey that are now usually referred to the Potomac formation, but they had few facts on which to base their age determination. Thus W. B. Rogers[1] described these beds as Upper Secondary, and provisionally referred them to the Upper Jurassic, though he later[2] suggested that they might form a "passage-group analogous to the Wealden of British geology." Tyson[3] also described a part of the same series under the designation of "iron ore clays" which he at first referred to the Cretaceous, but afterward[4] placed "at least as low as the Oolitic." According to Dawson[5] and Fontaine[6] Tyson considered that these beds belonged to the Wealden, but he seems not to have published that opinion. In 1886 Mr. W J McGee[7] named and described the Potomac as a distinct formation including the above mentioned beds that had been discussed by Rogers and Tyson. Its determination as of Lower Cretaceous age has been mainly due to the paleobotanical work of Professors L. F. Ward[8] and W. M. Fontaine.[9]

In 1869 Gabb and Whitney[10] defined the Shasta group of California, stating that "It contains fossils seemingly representing ages from the Gault to the Neocomian, inclusive." The Shasta group has ever since been referred to the Lower Cretaceous, and subsequent investigations have only confirmed the

[1] Report of Prog. of Geol. Surv. of Va. for 1840, Richmond, 1841. Idem for 1841, Richmond, 1842. Both reprinted in Geology of the Virginias, 1884, pp. 413–546.

[2] Proc. Bost. Soc. Nat. Hist., Vol. XVIII, 1875, p. 105.

[3] First Rept. State Agricultural Chemist of Md., pp. 41–43, Annapolis, 1860.

[4] Second Rept. State. Agri. Chemist, p. 54, Annapolis, 1862.

[5] Trans. Roy. Soc. Canada, Vol. III, 1885, sec. 4, p. 18.

[6] Monograph U. S. Geol. Surv., No. 15, p. 5.

[7] Rept. of Health Officer for the Dist. of Columbia for 1885, pp. 23–25; Am. Jour. Sci., 3d ser., Vol. XXXV, 1888, pp. 120–143.

[8] Am. Jour. Sci., 3d ser., Vol. XXXVI, 1888, pp. 119–131.

[9] Monograph 15, U. S. Geol. Surv., 1889. See also many subsequent articles by both authors and by McGee, Darton, White, Marsh, and Clark listed in the accompany bibliography.

[10] Palæont. of California, Vol. II, p. xiv.

original suggestion as to its age. The stratigraphy and paleontology of the Shasta beds have been described or discussed by Gabb, Becker, White, Diller, Turner, Fairbanks, and Stanton.

Soon after the definition of the Shasta, Richardson[1] described strata in the Queen Charlotte Islands that were recognized by Billings from the invertebrate fossils as in part the equivalent of the Shasta, and on the evidence of a few plants were assigned to either the Jurassic or the Lower Cretaceous by Dawson. The fauna of these beds and of their equivalents on the mainland of British Columbia has since been described by Whiteaves, who regards them as not later than the Gault.

A few years later a series of fresh-water coal-bearing beds, the Kootanie formation, in the Rocky Mountain region of southern Canada, was recognized and defined by Dr. Geo. M. Dawson. The accompanying flora was studied by Sir William Dawson, who determined its age to be Lower Cretaceous and published the first account[2] of the formation in connection with the description of the flora. In 1887, the coal-bearing rocks of Great Falls, Mont., were referred to the Kootanie by Professor J. S. Newberry,[3] who later discussed the flora more fully and pointed out its close relationship with the flora of the Potomac. The possible occurrence of beds of the same age in the Black Hills, South Dakota, has been shown by Professor L. F. Ward[4] on the evidence of cycads and a few other plants of Lower Cretaceous aspect in beds that have formerly been referred to the Dakota.

Before this time and soon after the Potomac formation became known, Smith and Johnson[5] had described the Tuscaloosa formation in Alabama. It is now correlated with the upper portion of the Potomac or the Raritan beds.

[1] Geol. Surv. of Canada, Rept. of Progress for 1872–3, pp. 32–65.

[2] Science, Vol. V, 1885, p. 31; Trans. Roy. Soc. Canada, Vol. III, 1885, sec. 4, pp. 1–22; idem, Vol. X, 1892, sec. 4, pp. 79–93.

[3] School of Mines Quarterly, Vol. VIII, 1887, pp. 327–330; Am. Jour. Sci., 3d ser., Vol. XLI, 1891, pp. 191–201.

[4] Jour. Geol., Vol. II, 1894, pp. 250–266.

[5] Bull. U. S. Geol. Surv., No. 43, 1887, p. 95.

From this review it is seen that the Lower Cretaceous formations now known in the United States are the Comanche series of the Texan region, the Shasta group (including Knoxville and Horsetown beds) of the Pacific Coast, the Kootanie of Montana and possibly of the Black Hills, the Potomac of the Atlantic coastal plain, and the Tuscaloosa of the Gulf border. Only the first two are marine formations. In our comparisons of these formations it will not be necessary to enter into minute details of stratigraphy and lithology, since the most general descriptions will show that in most cases we have to deal with contrasts rather than with resemblances. This is true not only when the marine beds are compared with the non-marine, but also when the two marine formations are compared with each other, or the Potomac is compared with the Kootanie. In the descriptions that follow, mainly summarized from the latest published accounts, the principal characteristics of each formation are given, beginning with the fresh-water beds. The statements concerning the invertebrate faunas embody more of the results of my own studies.

GEOLOGIC DESCRIPTION OF THE FORMATIONS.

The Potomac formation.—This term was originally applied by McGee to certain non-marine beds in Maryland, the District of Columbia, and Virginia, resting against the old crystalline rocks of the Piedmont region, and unconformably overlain by marine Upper Cretaceous deposits. The Potomac as thus defined is composed of irregular deposits of variegated clays, sand, arkose, pebbles, and bowlders, with local lenses of iron ore and lignitic seams. The sand and arkose are sometimes indurated, but frequently are unconsolidated deposits. In general, the arenaceous deposits seem to predominate in the lower part of the series and argillaceous beds in the upper, though no single stratum retains the same lithologic character over any considerable area. The estimates of thickness vary from 500 or 600 feet (McGee) to 1175 feet (Ward). Professor Ward,[1] who has

[1] See 15th Ann. Rept. U. S. Geol. Surv., pp. 313–397, and 16th idem, pp. 469–540.

studied the stratigraphy and the flora of the Potomac in great detail, retains under that name all the strata originally included in it, and also makes it comprise all the beds that have been named the Raritan formation, extending from Maryland across Delaware and New Jersey to the islands off the southern coast of New England. That is, he makes it coextensive with Dr. White's[1] non-marine division of the Cretaceous of the Atlantic border region which was believed to consist of two distinct formations, separated by a time interval that marked the distinction between Lower and Upper Cretaceous. Though assigning these beds all to a single formation Professor Ward recognizes in it six distinct "series," as follows:

Potomac:
- 6. Albirupean [in part equivalent to Raritan].
- 5. Iron Ore,
- 4. Aquia Creek,
- 3. Mount Vernon,
- 2. Rappahannock,
- 1. James River.

Each of these divisions, excepting No. 5, is, according to the author cited, characterized by a distinct florula altogether constituting a flora of from 800 to 1000 species. Detailed discussions and comparisons of this flora are contained in the articles above referred to in the fifteenth and sixteenth annual reports of the U. S. Geol. Survey. From these it appears that while the whole formation is referred to the Lower Cretaceous the flora of the lower beds, in which the earliest known dicotyledons appear, has Jurassic affinities, and is related to the Wealden flora. There is a progressive change, the modern types predominating more and more until in the uppermost beds (No. 6) the plants show a marked affinity to the Upper Cretaceous Cenomanian flora. An interesting comparison of the Potomac flora with the Lower Cretaceous flora of Portugal, shows that while they have but few species in common the general characters of the two floras are very similar, and as Professor Ward remarks, "the lower Cretaceous flora of Portugal is, botanically speaking, a very close repetition of that of America." This fact is in interesting agreement

[1] Bull. U. S. Geol. Surv., No. 82, pp. 74–100.

with other independent sources of evidence, for the Portuguese plant beds are interstratified with strata carrying marine faunas that are, as we shall see, closely related to the fauna of the Comanche series, and one of the lower horizons in the Comanche has yielded fossil plants closely connected with the flora of the lower Potomac.

Invertebrate fossils are remarkably scarce in the Potomac, and the few that have been found do not afford any definite evidence as to the age of the beds. The only mollusks known from the lower horizons developed in Maryland and Virginia, are a few internal casts apparently belonging to small simple forms of Unio, whose only geological value is to show the fresh-water origin of the beds. In New Jersey, besides some Unios that probably came from a much later formation, five species of mollusks have been reported from the Raritan formation.[1] They have been referred to Astarte, Corbicula, Gnathodon, and Ambonicardia (gen. nov.), but not one of them is well enough preserved to show generic characters, and in invertebrate paleontology, at least, age determinations, based on new species of doubtful genera, are worthless.

Vertebrate fossils have been collected from the Lower Potomac in a limited area between Washington and Baltimore. One species based on a tooth, *Astrodon Johnsoni*, has been described by Dr. Leidy, and Professor Marsh[2] has named five others: *Pleurocoelus nanus*, *P. altus*, *Priconodon crassus*, *Allosaurus medius*, and *Coelurus medius*. He states that associated with these there are remains of crocodiles and tortoises, of Jurassic types, some fishes and a few mollusks. Also that "The fossils here described, and others from the same horizon seem to prove conclusively that the Potomac formation in its typical localities in Maryland is of Jurassic age and lacustrine origin." The genera Allosaurus and Coelurus were originally described from the Atlantosaurus beds (Jurassic) of the Rocky Mountain region, and Pleurocoelus has since been found in the same beds repre-

[1] Monograph 9, U. S. Geol. Surv., pp. 22–28.

[2] Am. Jour. Sci., 3d. ser. Vol. XXXV, 1888, pp. 89–94.

sented by a Potomac species. According to Lydekker Pleurocoelus also occurs in the Wealden of England. In recent papers Professor Marsh[1] has attempted to establish the Jurassic age of the whole Potomac formation in its broadest sense. He correlates it by the relationship of the vertebrate faunas on the one hand with the Atlantosaurus beds, and on the other with the European Wealden, asserting that they are homotaxial equivalents. Assuming that the Atlantosaurus beds are Jurassic, it consequently follows, according to his reasoning, that the Wealden and the Potomac are also Jurassic. But even admitting that the vertebrate faunas are so closely related as to establish the equivalence of the deposits in these three widely separated regions, the correlation can apply only to the beds in which the fossils occur, and in the Potomac they have so far been found only in the lower portion. Recent stratigraphic studies by Professor W. B. Clark and Mr. Arthur Bibbins on the Potomac in Maryland, have an important bearing on this question. A preliminary statement of their results, including a new classification of the deposits, was published[2] some months ago, and a more detailed account has been issued since the present paper was first written.[3] Their most important results are summarized as follows:

"It is the conclusion of the authors, founded upon a detailed stratigraphic study of the Potomac group, that all the beds which have afforded dicotyledonous types of plant life are above those from which Professor Marsh has obtained vertebrate remains, and moreover, that a marked unconformity exists between the two series of deposits. . . . .

"The several formations into which the larger unit of the Potomac group has been divided, are as follows:

[1] Am. Jour. Sci., 4th ser., Vol. II, 1896, pp. 295–298, 375–377, 433–447. See also articles on the same subject by Hollick, Ward, Hill, and Gilbert, Science, Vols. IV and V, 1896, 1897.

[2] Physical Features of Maryland; Maryland Geol. Surv., Vol. I, Pt. 3, pp. 56–59, April 1897.

[3] Jour. Geol., Vol. V, pp. 479–506, July–Aug. 1897.

Lower Cretaceous	Raritan Formation		Potomac.
	Patapsco	"	
Upper Jurassic (?)	Arundel	"	Group"
	Patuxent	"	

According to these authors all of the Potomac vertebrates that have been recorded have come from the Arundel formation, while practically the whole of the Potomac flora occurs in higher horizons above the principal unconformity which separates the Patapsco from the Arundel. All of Professor Ward's plant-bearing "series" below the Albirupean are believed to be local subdivisions and variations of the Patapsco formation. The underlying beds are doubtfully assigned to the Upper Jurassic on the authority of Professor Marsh's determination of the affinities of the vertebrates. It has been shown, however, that his comparisons are chiefly with the Wealden fauna, and if the difficult stratigraphy of the Potomac has now been correctly determined the evidence tends to prove the post-Wealden age of the principal plant-bearing horizons.

There have long been differences of opinion as to the age of the Wealden, and it may well be that it is partly Jurassic, but its constantly close association with the Cretaceous, and the fact that where it is present the lowest marine beds of the Neocomian are always absent, are strong arguments for regarding it as a non-marine facies of the Neocomian. If all the Wealden deposits are transferred from the Cretaceous to the Jurassic because the dinosaurs are closely related to those of the Jurassic, then we know practically nothing of the land fauna of the Lower Cretaceous, and no one can say whether the dinosaurs that must have lived in early Cretaceous time, were very different from those of the Jurassic or not. Professor Marsh's statements may be fairly interpreted to mean that the age of the Atlantosaurus beds is dependent on that of the Wealden, and if the latter is Cretaceous the former are also. There is nothing in the stratigraphic relations of the Atlantosaurus beds that would prevent their reference to the Lower Cretaceous, for they are everywhere immediately overlain by Upper Cretaceous strata.[6] However-

[6] There is a possible exception to this in the Black Hills of South Dakota, where

ever these questions may be finally decided, it is evident that the discussion as to the Potomac formation is not so much on its correlation with deposits elsewhere as on the more general question of the upper limits of the Jurassic.

The Tuscaloosa formation.—The beds known under this name have their principal development in Alabama, extending thence eastward into Georgia and westward into Mississippi. According to Prof. E. A. Smith[1] the formation consists of "heavy bedded purple and mottled and gray clays in the lower parts, alternating with more distinctly stratified clays containing an abundance of plant remains, chiefly in the form of leaf impressions. Above these clayey beds are sands of various colors, white, yellow, gray, pink, and purple, usually micaceous and strongly cross-bedded. In many places irregular pockets of small angular chert pebbles are interbedded with the sands, but these pebble beds make only a very small proportion of the strata. In places also beds of dark red and mottled clay occur in the upper part of the formation." In the eastern part of the area it rests on ancient crystalline rocks while farther west it laps up on the Paleozoic sediments. The overlying beds are of Upper Cretaceous age.

The thickness of the Tuscaloosa is estimated at 1000 feet.

Lithologically and stratigraphically the Tuscaloosa is seen to correspond closely with the Potomac and the evidence of the flora leads to the same correlation. Professor Smith[2] publishes a list of 35 species of fossil plants determined by Professor Ward, who compares them with the Amboy Clay (*i. e.* Uppermost Potomac) flora. In later publications Professor Ward[3] definitely correlates the Tuscaloosa with the Amboy and Raritan clays, suggesting that possibly one of the older horizons of the Potomac may also be represented in Alabama. No animal remains

Professor Ward obtained plants that he regards as Lower Cretaceous, and the Atlantosaurus fauna has also been found in this same region, but what relation the plant-beds have to the vertebrate horizon, and whether the plants and vertebrates do not really occur in the same bed has not been determined.

[1] Rep. on Geol. of the Coastal Plain of Ala., pp. 307–308, Montgomery, 1894.

[2] *Ibid.*, p. 348.

[3] 15th Ann. Rept. U. S. Geol. Surv., pp. 337–338; 16th Ann. Rept., p. 470.

have been reported from these southern beds. According to Mr. N. H. Darton[1] the Potomac deposits are practically continuous along the whole Atlantic coastal plain until they connect with the Tuscaloosa. It is evident that conditions of deposition were remarkably uniform throughout this long coastal border region during Potomac time but the earlier part of the epoch is recorded by deposits now visible only in the middle portion of the area. The northern and southern ends either did not receive deposits until towards the close of the epoch or else the early deposits were overlapped and concealed by the later beds.

The Kootanie formation.—A somewhat detailed description of the typical area of the Kootanie is given by Dr. Geo. M. Dawson.[2] It is found in the Rocky Mountains of Canada between latitudes 49° and 51° 30′. The beds there have a total estimated thickness of over 7000 feet and consist chiefly of shales and sandstones of very varied texture and appearance, with beds of coal. The Canadian localities have yielded a flora[3] of about 27 species which show by identical and allied species a very close relationship with the Potomac. No animal remains have been reported excepting one imperfect specimen of a Goniobasis indicating fresh waters, and a fragment of a belemnite which was very probably derived from an older formation.

In the United States the Kootanie occurs at Great Falls, Montana, near which place a thick coal bed in the formation is mined. The section has been described by Mr. W. H. Weed[4] who states that the Kootanie " is a series of rapidly alternating sandstones and clay shales with few and thin beds of impure limestone. Individual beds are inconstant, the heavy ledges of heavy sandstone passing laterally into arenaceous clays and *vice versa*."

The top of the formation is not clearly defined but the thickness is evidently several hundred feet. About 38 species of fossil

[1] Bull. Geol., Soc. Am., Vol. VII, 1896, pp. 514–517.

[2] Rept. Geol. Surv. of Canada for 1885, Rept. B. A more general account in Am. Jour. Sci., 3d ser., Vol. XXXVIII, pp. 120–127.

[3] Trans. Roy. Soc. Canada, Vol. III, 1885, Sec. 4, pp. 1–10. Idem, Vol. X, 1892, Sec. 4, pp. 79–93. Idem, Vol. XI, 1893, Sec. 4, p. 11.

[4] Two Montana coal fields. Bull. Geol. Soc. Am., Vol. III, 1892, pp. 301–323.

plants have been listed or described from the Kootanie of this neighborhood by Professors Newberry[1] and Fontaine.[2] These show a close connection with the not distant Canadian Kootanie, and more than half of them (21 out of 38) have also been identified from the Potomac. It is noteworthy, however, that no dicotyledons have been found in the Kootanie, thus indicating that the higher horizons of the Potomac are possibly not represented there. Invertebrates are represented in the Great Falls area only by a few imperfect specimens of Unio. A higher bed which may belong to a later formation has yielded undescribed species of Neritina, Goniobasis, and Corbula (?).

It is evident that the Kootanie and Potomac were laid down in distinct basins of fresh and brackish waters and that the floras prove that they are in part homotaxial equivalents.

The Shasta group.—This general name was given by Gabb and Whitney to all the Lower Cretaceous rocks of California. In 1885 Dr. C. A. White[3] and Dr. G. F. Becker[1] named two subdivisions of the Shasta, the Knoxville and the Horsetown beds, that have since been generally recognized. Detailed sections have been described by Turner,[4] Diller[5] and the present writer[6] who has recently reviewed the geology of the Knoxville beds and described their fauna.

The Shasta is a marine formation distributed along the western side of the Sacramento valley and in the coast ranges of California, Oregon, and Washington. The lower divisions have been recognized as far north as latitude 35°.

"Dark clay shales greatly predominate over all other kinds of rocks in the Knoxville beds, but there is also considerable sandstone, usually in thin beds. In some places the lower part of the formation consists of alternations of shale and sandstone,

[1] Am. Jour. Sci., 3d ser., Vol. XLI, 1891, pp. 191–201.

[2] Proc. U. S. Nat. Museum, Vol. XV, 1892, pp. 487–495.

[3] Bull. U. S. Geol. Surv., Nos. 15 and 19.

[4] Bull. Geol. Soc. Am., Vol. II, 1891, pp. 303–314.

[5] Am. Jour. Sci., 3d ser., Vol. XL, 1890, pp. 476–478. Bull. Geol. Soc. Am., Vol. IV, 1893, pp. 205–224. Idem, Vol. V, pp. 435–464.

[6] Bull. U. S. Geol. Surv., No. 133, 1896.

or calcareous material, in bands only a few inches thick. There are also occasional thicker bands of sandstone, and sometimes massive conglomerates. The larger bodies of shale frequently contain many calcareous concretions, and such concretions are sometimes found even in the coarse conglomerates. More rarely there are larger bodies of limestone, several feet in thickness, but they do not form continuous beds of any great extent. The conglomerates also appear to be local deposits of no great length, though sometimes of very considerable thickness." The overlying Horsetown beds have essentially the same lithologic character and are distinguished mainly by marked differences in the fauna—especially by the absence of Aucella and the greater abundance and variety of the ammonites. Where the base of the Shasta has been observed it rests on metamorphic rocks of undetermined age. It is conformably overlain by the upper Cretaceous Chico formation which in its basal portion is probably as old as the Cenomanian.

The Lower Cretaceous has an enormous thickness at some localities on the Pacific coast. A section on Elder Creek, Tehama county, Cal., measured by Mr. Diller, showed about 20,000 feet of Knoxville and 6000 feet of Horsetown beds without any evidence of duplication of strata. This thickness is exceptional, though other localities in the same region show apparent thicknesses of 12,000 to 15,000 feet.

Although the Shasta group is of marine origin it has yielded a number of land plants from several different horizons ranging from the upper third of the Knoxville to near the top of the Horsetown beds. Professor Fontaine has recognized twenty-six different forms among them. He says that "all have their nearest relations in Lower Cretaceous forms, and there is no plant that would indicate an age different from Lower Cretaceous." A large proportion of the species occur in the Potomac and a few are found in the Kootanie and in the Comanche series, none of which offers any other means of direct comparison with the Shasta. Here, as in the Kootanie, no dicotyledons have been found.

In my recent work on the Knoxville fauna the following species are described:

Rhynchonella schucherti S.
R. whitneyi Gabb
Rhynchonella sp.
Terebratula sp.
Terebratula californica S.
Ostrea sp.
Anomia senescens S.
Spondylus fragilis S.
Lima multilineata S.
Pecten californicus Gabb?
Pecten sp.
Pecten complexicosta Gabb
Avicula whiteavesi S.
Aucella piochii Gabb
A. piochii var. ovata S.
A. crassicollis Keyserling
Inoceramus ovatus S.
Modiola major Gabb
Myoconcha americana S.
Pinna sp.
Arca textrina S.
Pectunculus? ovatus S.
Nucula gabbi S.
Nucula storrsi S.
Leda glabra S.
Cardiniopsis unioides S.
Solemya occidentalis S.
Astarte corrugata S.
Astarte californica S.
Astarte trapezoidalis S.
Opis californica S.
Lucina ovalis S.
L. colusaensis S.
Cyprina occidentalis Whiteaves
Solecurtus? dubius S.
Corbula? persulcata S.
Corbula filosa S.
Dentalium californicum S.
Helcion granulatus S.
Fissurella bipunctata S.
Pleurotomaria sp.
Turbo paskentaensis S.
T. wilburensis S.
T. trilineatus S.
T. colusaensis S.
T. morganensis S.
T.? humerosus S.
Amberleya dilleri S.
Atresius liratus Gabb
Turritella sp.
Hypsipleura? occidentalis S.
Hypsipleura gregaria S.
Cerithium paskentaensis S.
C. strigosum S.
Cerithium sp.
Aporrhais sp.
Phylloceras knoxvillense S.
Lytoceras batesi (Trask)
Desmoceras californicum S.
Desmoceras sp.
Olcostephanus mutabilis S.
O. trichotomus S.
Hoplites hyatti S.
H. storrsi S.
H. angulatus S.
H. crassiplicatus S.
H. dilleri S.
Perisphinctes sp.
Diptychoceras? sp.
Crioceras latus Gabb
Aptychus? knoxvillensis S.
Belemnites impressus Gabb
Belemites tehamaensis S.
Belemites sp.

To quote again from my previous paper: "When studying the Knoxville fauna as a whole, either in the field or from aver-

age collections, one is impressed with the excessive preponderance of the Aucellæ, so far as number of individuals is concerned. In many places they are so abundant that they must have actually monopolized the sea bottom, crowding out everything else.

"Considering the fauna as an assemblage of species, the proportion of brachiopoda, though there are so few, is somewhat greater than in other American Cretaceous faunas. Among the mollusca the variety of forms of Turbinidæ is noteworthy. The proportion of ammonoids is also quite large, and there is an unusual development of the genus Hoplites."

The Aucellæ do not pass above the Knoxville, or to speak more accurately, the top of the Knoxville is drawn at the upper limit of the Aucella beds. Several other Knoxville species, however, do pass up into the succeeding Horsetown fauna. This fauna has not yet been revised and a considerable number of undescribed species are known in recent collections, but the following lists, though incomplete, will give a correct idea of its general character. In the lower part of the Horsetown ammonites are locally very abundant, the genera Lytoceras and Phylloceras being especially well represented in individuals. The following species occur in this portion of the series:

Pentacrinus sp.
Rhynchonella sp.
Pecten operculiformis Gabb
Plicatula variata Gabb
Avicula whiteavesi Stanton
Inoceramus sp.
Nemodon vancouverensis (Meek)
Trigonia æquicostata Gabb
Trigonia leana Gabb ?
Opis sp.
Eriphyla sp.
Protocardia sp.
Pleuromya papyracea Gabb
Lunatia avellana Gabb
Potamides diadema Gabb
Helicaulax ? bicarinata Gabb
Actæon impressus Gabb
Lytoceras batesi (Trask)
Phylloceras onoense Stanton
Hoplites remondi (Gabb)
Olcostephanus traski (Gabb)
Desmoceras hoffmanni (Gabb)
Crioceras latus Gabb
Crioceras percostatus Gabb
Ancyloceras remondi Gabb
Helicancyclus æquicostatus Gabb
Diptychoceras lævis Gabb
Belemnites impressus Gabb

The few fossils that have been collected from the middle portion of the Horsetown do not show any decided change in

the fauna until the extreme upper beds are reached, when a more abundant fauna appears that shows a blending with the succeeding Upper Cretaceous Chico fauna. These upper Horsetown beds have yielded the following species:

Rhynchonella sp.
Exogyra parasitica Gabb
Pecten operculiformis Gabb
Mytilus quadratus Gabb
Mytilus cf. lanceolatus Sowerby
Cucullæa truncata Gabb
Nemodon vancouverensis (Meek)
Leda translucida Gabb
Trigonia æquicostata Gabb
Trigonia leana Gabb
Meekia sella Gabb
Meekia navis Gabb
Meekia radiata Gabb
Chione varians Gabb
Tellina matthewsonii Gabb
Mactra sp.
Pleuromya papyracea Gabb
Panopæa concentrica Gabb
Lunatia avellana Gabb
Liocium punctatum Gabb
Actæonina californica Gabb
Ringicula varia Gabb
Desmoceras hoffmanni (Gabb)
Desmoceras cf. beudanti (Brongniart)
Haploceras breweri (Gabb)
Lytoceras sacya Forbes
Schloenbachia inflata (Sowerby)
Acanthoceras cf. mammillare (Schloth.)
Belemnites sp.

After weighing the available paleontologic evidence and making all practicable comparisons with foreign Mesozoic fossils the conclusion was reached that the whole of the Knoxville is referable to the Neocomian and that the Horsetown includes all the rest of the Lower Cretaceous and possibly extends up into the Upper Cretaceous.

The abundance of Aucellæ gives the Knoxville fauna a decided boreal appearance, for the distribution of that genus has been considered essentially circumpolar. Some of the ammonitic types also point in the same direction, but the genera Lytoceras and Phylloceras are also represented, and these are the genera that Neumayr considered especially characteristic of the southern or tropical zone. With the disappearance of Aucella the fauna of the Horsetown becomes almost purely southern in type, so far as the ammonites are concerned, as Professor J. P. Smith[1] has stated; but this change can hardly be attributed to a change in climate, for it will be remembered that Aucella beds occur as

[1] Mesozoic Changes in the Faunal Geography of California, JOUR. GEOL., Vol. III, 1895, pp. 381–382.

far south as the Himalayas in India and almost to the tropics in Mexico. Besides, the fossil plants of both divisions of the Shasta, as well as those of the more northern Kootanie, indicate at least a warm temperate climate.[1] The facts seem to support Dr. Kossmat's[2] opinion that Neumayr exaggerated the influence of climate on the distribution of ammonites [and other Mesozoic invertebrates as well], and that the climatic influence was of little importance when compared with geographic relations, the presence or absence of opportunities for free communication, etc. Neumayr[3] himself referred the California Cretaceous to his Indo-Pacific region, and spoke of the persistent conservative character of the Mesozoic faunas of that region. The earliest Cretaceous deposits are apparently not preserved on the Asiatic side of the Pacific, but beginning with the Upper Cretaceous beds, usually classed as Cenomanian, on about the horizon of the uppermost Horsetown beds, very closely related faunas are widely distributed around the borders of the great Pacific basin. They occur in southern India, Japan, Saghalin, Queen Charlotte Islands, Vancouver, and, according to Steinmann,[4] on the west coast of Chile. While Lower Cretaceous deposits are not so widespread in that region, the character and distribution of their fauna down the west coast of North America seem to indicate that the Pacific was then the home of a uniform fauna, and that it was directly connected with the boreal sea that covered Russia and Siberia, but was not in communication with the Atlantic. This subject can be discussed more satisfactorily after reviewing the Cretaceous of the Texas region.

The Comanche series.—In area and in faunas the greatest development of the Lower Cretaceous in the United States is the Comanche series of the Texan region. Its outcrops extend from western Arkansas through southern Indian Territory to Denison and Preston, thence southward through Fort Worth, Austin, and

[1] Sir J. W. Dawson, Trans. Roy. Soc. Canada, Vol. X, 1892, Sec. 4, pp. 81–82.

[2] Jahrb. der k. k. geol. Reichsanstalt, 1894, Bd. 44, p. 476.

[3] Erdgeschichte, Bd. 2, p. 391, 1883.

[4] Neues Jahrb. f. Mineral., Geol. und Paläont., Beilage Bd. 10, 1895, pp. 1–118.

San Antonio to the Rio Grande at Del Rio, covering large areas west of that line. It is known to underlie a large part of Mexico, extending as far west as Arivechi in Sonora. Small outlying areas occur in southern Arizona, at El Paso, Texas, in eastern New Mexico, in Oklahoma, and in southern Kansas. The stratigraphic details have been published mainly by Messrs. R. T. Hill, J. A. Taff, E. T. Dumble, W. F. Cummins, T. W. Vaughan, and C. S. Prosser.

The main features of Mr. Hill's classification of the deposits are as follows :

Comanche series	Washita	Shoal Creek limestone, Denison beds, Fort Worth limestone, Preston beds.
	Fredericksburg	Caprina (Edwards) limestone, Comanche Peak limestone, Walnut clays.
	Trinity	Paluxy sands, Glen Rose limestone and clays, Trinity sands.

This list gives the principal recognized subdivisions and indicates the lithologic character of the section in central Texas. Calcareous sediments of varying texture and composition largely predominate over all other kinds, thus contrasting strongly with the Shasta deposits. Considerable beds of sand are locally developed in the lower or Trinity division, and in the middle of the Washita clays and sandy layers usually predominate, but as a rule much more than half of the total thickness of the Comanche series consists of calcareous beds. Near the borders of the Comanche sea the limestones decrease in relative thickness or disappear entirely. At El Paso they form but a small proportion of the section, and in the Tucumcari region of New Mexico and in southern Kansas the rocks are all sandstones and clay shales. In the latter region the total thickness is only about 200 feet, and apparently the Washita division is the only one represented. In central Texas the entire series has a thickness of about 1500 feet, which increases southwestward, until

in northern Chihuahua it reaches 4000 feet, as estimated by Dr. C. A. White,[1] and still farther south very much greater thicknesses have been reported. Lithologically the Comanche series as a whole contrasts strongly with the Cretaceous rocks of all other parts of the United States, and indeed of North America, excepting Mexico, which is directly connected with the Texan area. Judging from the descriptions, lithologically similar Cretaceous rocks are developed to some extent in the northern part of South America and in southern Europe. We must go to these regions also, and especially to Portugal and Spain, as Mr. Hill has pointed out, to find closely related faunas.

Fossil plants have been obtained from two horizons, one in the Glen Rose beds of the Trinity division, about 250 feet above the base of the series, and the other in the so-called Cheyenne sandstone, at the base of the Cretaceous section in southern Kansas, but apparently within the Washita division. The plants from the lower horizon, which are directly associated with an abundant marine fauna, have been described by Professor Fontaine.[2] He recognized twenty-three distinct forms, consisting mainly of conifers and cycads, with a fern, an Equisetum, and a few forms of uncertain affinities. Of these seven are represented by identical and six by similar species in the Potomac, four occur in the Wealden of Europe, two in the Urgonian, with an additional one represented by a similar form, and six are peculiar to the Glen Rose. In discussing the age and affinities of these plants Professor Fontaine says: "The plants found at Glen Rose show, so far as can be judged from so imperfect a collection, that the Trinity flora finds its closest resemblance in the older portion of the lower Potomac. There is, however, this important difference: no trace of angiosperms, even the most archaic, has been found in the Texan region. We have only the four elements of the typical Jurassic flora. This, then, makes the Trinity flora somewhat older than that of the oldest Potomac. The absence of angiosperms and the presence of the forms that

[1] Am. Jour. Sci., 3d ser., Vol. XXXVIII, 1889, pp. 440–445.

[2] Proc. U. S. Nat. Museum, Vol. XVI, 1893, pp. 261–282.

are found indicate decidedly that the Trinity flora is not younger than the earliest stage of the Cretaceous. The number of plants found to be identical with certain of those of the oldest Potomac shows that there is little difference in the age of the two formations. The plant-bearing portion of the Trinity is somewhat older than the basal Potomac strata, but the difference in age cannot be great."

In this reasoning it seems to me that too much stress is laid on negative evidence, the absence of angiosperms. The present habits and distribution of plants do not warrant the assumption that a small collection containing only twenty-three species from a very limited area would necessarily include all the important types of plants living at the time they were entombed. The still more striking incompleteness of the Lower Cretaceous faunas will be discussed beyond. It will be remembered that the Kootanie flora and the plants from the Shasta, which were also compared with the Potomac flora, likewise showed the absence of dicotyledons and this was true even in the Horsetown beds which are known from their fauna and stratigraphic position to be far above the base of the Lower Cretaceous.

Among the plants from the Washita horizon in southern Kansas, Dr. Knowlton[1] has recognized seven species of which five are dicotyledons and two are conifers. The species identified had before been found only in the Dakota group in a flora usually assigned to the Cenomanian. It has been shown by Cragin,[2] however, that a part of the beds referred to the Dakota probably belongs to the Comanche series. At all events it is certain that the upper part of the Comanche approaches the Upper Cretaceous in character and it probably is not far from the horizon of the uppermost Potomac beds.

The vertebrates obtained from the Comanche series are few and mostly fragmentary. The descriptions and determinations of Williston,[3] Cragin,[4] and Cope[5] show the presence of fishes,

[1] In a paper by Mr. HILL, Am. Jour. Sci. 3d. ser. Vol. L, 1895, pp. 212–214.

[2] Am. Geologist, Vol. XVI, 1895, pp. 162–165.

[3] Kansas Uni. Quarterly, Vol. III, 1894, pp. 1–4.

[4] Colorado College Studies, Vol. V, 1895, pp. 69–73.

[5] Jour. Acad. Nat. Sci. Phila., Vol. IX, 1895, pp. 443–447.

turtles, crocodiles, and plesiosaurs but they have not furnished any very definite evidence as to the age of the beds. One of the fishes (described by Cope) came from the Glen Rose beds and another from an unknown locality in Texas. All the other vertebrates mentioned are from higher beds near Camp Supply, Oklahoma, and in southern Kansas. Fragmentary bones that are supposed to be dinosaurs but have not been definitely identified have been collected in the Trinity sands by Mr. Hill.

The invertebrate fossils are very numerous throughout almost all of the series above the basal Trinity sands, and constitute several distinct subfaunas though all are connected by species that pass from one zone to another and a few species range through a large part of the series. The species have been mostly described in various books and papers by Roemer, Giebel, Marcou, Shumard, Gabb, White, Hill, and Cragin. The revision of the invertebrate species with the description of new forms contained in recent collections on which I am at present engaged has not progressed far enough to enable me to give complete lists of the fossils of each zone but the general features of the fauna can be profitably discussed and some interesting comparisons can be made.

Mr. Hill's[1] reviews of the subfaunas of the Trinity division and of the Caprina limestone in the Fredericksburg division afford a basis for comparing these horizons with other Cretaceous beds. The list given for the Trinity (Glen Rose) includes about forty invertebrate species and this number will be considerably increased by the study of recent collections. The following characteristic forms, mostly from the same horizon as the Glen Rose plants, are the most important for our present purpose:

Ostrea franklini Coquand	Requienia cf. texana Roemer
Trigonia stolleyi Hill	Monopleura cf. marcida White
Trigonia crenulata (Lam.) Roemer	Monopleura cf. pinguiscula White
Trigonia lerchi (Hill)	Cyprina sp.
Trigonia n. sp.	Natica (Lunatia) pedernalis Roemer

[1] Proc. Biol. Soc. Washington, Vol. VIII, 1893, pp. 9–40, 97–108.

Tylostoma sp.
Glauconia branneri (Hill)
Glauconia cf. helvetica (Pictet and Renevier)
Glauconia cf. picteti Coquand
Nerinea sp.
Neumayria ? ? walcotti Hill
Stoliczkaia justinae (Hill)

Excepting the ammonites and the last two species of Trigonia these forms are all very abundant in certain layers and give character to the fauna. The Ostrea is a simple form of little diagnostic value mentioned merely on account of its abundance. The Trigonias represent three groups, two of which, scabræ and quadratæ, are characteristic of the Cretaceous and the other, glabræ, occurs in both Jura and Lower Cretaceous. Requienia and Monopleura are not known outside of the Cretaceous and are found in the Urgonian and higher horizons of Portugal and other southern European countries.[1] *Natica piedernalis* is very like *N. simillinus* Choffat of the Urgonian of Portugal, and Choffat speaks of the great abundance of large Naticas in that horizon, though similar forms also occur in the Valanginian (Lower Neocomian) of the same region. The species of Glauconia are all represented by very similar southern European forms ranging from the Urgonian to the Aptian and perhaps higher. The two species of ammonites are not well enough known to be compared satisfactorily but their nearest relatives apparently are Lower Cretaceous species.

Several other forms have representative species in southern Europe but when the comparisons are all made the final result is not a definite correlation of the lowest fossiliferous beds of the Trinity with any particular horizon of the Lower Cretaceous, though the evidence is clear that it cannot be earlier than the Lower Cretaceous and that it probably is not the base of the Cretaceous.

[1] For stratigraphy and related species mentioned in this discussion see CHOFFAT Recueil de Monog. Stratig. sur le Système Crétacique du Portugal, Lisbonne, 1885 Recueil de Monog. palèont., etc., 1886.

PICTET et RENEVIER. Fossiles du Terrain Aptien de la Perte du Rhone.
PICTET et CAMPICHE. Fossiles du Terrain Crétacé des environs de Sainte Croix
DE LORIOL et DE LORIÈRÈ. Fossilés du Neocomien supèrieur de Utrillas.
COQUAND, Monographie paléontologique de l'etage Aptien de l'Espagne.

In the lower part of the Fredericksburg division the Naticas and Tylostomas, in part identical with those of the Trinity continue to play an important part. Here we find the first beds of Gryphaea belonging to the series of species that have often been grouped under the single name *Gryphaea pitcheri* Morton, but which are now separated into several species. These Gryphaeas occur in immense numbers at intervals to the top of the Comanche. Other ostreidae such as Exogyra and Alectryonia have a great development of individuals representing several species. Echinoids, belonging to the genera Enallaster, Hemiaster, Epiaster, Holaster, Holectypus Pseudodiadema, Cidaris, and a few others are also numerous and continue in greater or less abundance in the calcareous beds to top of the series. Among other common forms are Cyprimeria, with difficulty distinguishable from Upper Cretaceous species, several species of Nerinea, Aporrhaidae, etc. Three important species of ammonites, *Engonoceras piedernalis* (von Buch), *Schloenbachia acutocarinata* (Shumard) and *S. trinitensis* (Gabb) also occur.

The Caprina limestone constituting the upper part of the Fredericksburg divison has an interesting and remarkable fauna consisting largely of Requienia, Monopleura, Ichthyosarcolites and other Chamidae, with Radiolites or Sphærulites, Nerinea, many other gastropods, corals, etc. The general assemblage of forms is very much like that in the "Schrattenkalk" or "Caprotina limestone" of the Urgonian and the similarity extends to specific forms in many cases. There is also a more superficial resemblance to the Upper Cretaceous "Hippurite" limestone and it was partly this resemblance that caused Roemer and Heilprin[1] to refer the Comanche series to the Upper Cretaceous. While it would perhaps not be justifiable to call the Caprina limestone Urgonian (as defined by Choffat) or to say that they are exact homotaxial equivalents yet such a statement could not be very far from the truth. The two faunas resemble each other in so many particulars that there must have been free communication between the two areas and the conditions of

[1] Proc. Acad. Nat. Sci. Phila., 1890, pp. 445–469.

marine life must have been very nearly the same in both but as we do not know where the faunas originated nor the direction and rate of migration we can not determine the exact time relations of the deposits.

In the Washita division many of the elements of the Fredericksburg fauna continue either unchanged or but slightly modified. Among identical species that occur in the lower beds of the Washita *Exogyra texana*, *Turritella seriatim-granulata* and *Schloenbachia acuto-carinata* may be mentioned. The *Engonoceras* group[1] of ammonites also reappears in the upper part of the division. Ammonoids are more abundant in the lower Washita (Preston and Forth Worth beds) than in any other part of the Comanche series, though only a few types are represented. Besides those already mentioned, the large *Pachydiscus brazoensis* (Shumard) and *Hamites fremonti* Marcou are abundant, and there is a large development of the genus *Schloenbachia*, mostly of the type *S. inflata* (Sowerby). These forms together with the large *Turrilites brazoensis* Roemer, if occurring in Europe would probably be taken to indicate either uppermost Gault or lowest Cenomanian. A large development of littoral forms in the Denison beds of northern Texas, in the Tucumcari region of New Mexico, and in southern Kansas also gives the fauna a rather modern aspect. But its close relationship with the fauna of the underlying Fredericksburg division and the fact that the next succeeding fauna, that of the Timber Creek beds, contains species of Acanthoceras and other types resembling those that are characteristic of the Cenomanian in Europe tend to place it lower in the Cretaceous system. The uppermost beds of the Washita may possibly be as late as the Cenomanian, but the lower beds in which Schloenbachia is so abundant can hardly be more recent than the Gault. However this point may be decided, the most natural major plane of division in the Texan

[1] This group including *Ammonites piedernalis* van Buch, frequently spoken of as "Cretaceous Ceratites," or as "Buchiceras," in the broad sense in which it was originally defined, is considered characteristic of the southern European or Mediterranean Cretaceous.

Cretaceous is at the top of the Comanche series, and this plane seems to coincide very closely with the top of the Potomac and the top of the Shasta.

It has already been mentioned that the Cretaceous of part of the west coast of South America has some resemblance to the Comanche series, but little is published about the stratigraphy, and in describing the fossils few attempts have been made to indicate the different horizons, so that it is now impossible to make close comparisons. In Peru *Schloenbachia acuto-carinata*, and several large Naticas and Tylostomas, occur with a few other forms related to Comanche species. Similarly in Columbia *Ptychomya buchiana* (Karsten), *Exogyra boussingaulti* d'Orb. and several others have representatives in the Comanche. It has been assumed by some authors that these forms lived in the Pacific basin, and that they prove that the Pacific and Atlantic were connected during Lower Cretaceous time.

By independent comparisons with European Cretaceous faunas—principally northern European in one case and southern or Mediterranean in the other—aided by stratigraphic relation with overlying beds and by the evidence of the fossil plants we have reached the conclusion that the Shasta group and the Comanche series were essentially contemporaneous deposits. And yet their faunas are almost totally distinct. This separateness of the two faunas has frequently been mentioned by Dr. White[1] and the present writer,[2] but the real character of the differences has not been clearly stated. The differences are not dependent on fine discrimination of closely related species. On the contrary, whole genera and in some cases much higher groups that are abundant and characteristic in one area are entirely absent in the other. The following table will exhibit some of the more striking contrasts:

[1] Bull. U. S. Geol. Surv., No. 15, 1885, pp. 30–31; *ibid.*, No. 82, 1891, pp. 180–198.

[2] Bull. Geol. Soc. Am., Vol. IV, 1893, p. 254; JOUR. GEOL, Vol. III, 1895, pp. 858–861; Bull. U. S. Geol. Surv., No. 133, 1896, pp. 27, 31; DILLER and STANTON; Bull. Geo. Soc. Am., Vol. V, 1894, p. 462.

	Comanche.	Shasta.
Echinoids.........	Very abundant in several horizons	Presence barely indicated at one locality in the Knoxville
Terebratula	Abundant in two beds	Rarely represented
Rhynchonella......	Absent	Locally abundant
Ostreidæ..........	Immensely abundant and represented by Ostrea, Gryphaea, Exogyra, and Alectryonia	Very scarce. A small Ostrea in the Knoxville and Exogyra at top of Horsetown
Aucella...........	Absent	Immensely abundant in the Knoxville
Trigonia..........	Common	Common, species not closely related
Rudistæ	Abundant in Caprina Limest.	Absent
Chamidæ	Abundant in Caprina Limest.	Absent
Cyprina	Very abundant	Rare
Protocardia	Large species abundant	One very small species of distinct type
Cyprimeria........	Abundant	Absent
Naticidæ..........	Large species abundant	One or two small forms common
Glauconia.........	Abundant	Absent
Turritella	Abundant	Very rare
Nerinea...........	Abundant	Occurrence doubtful
Actæonella	Locally abundant	Rare
Lytoceras ,........	Absent	Abundant
Phylloceras	Absent	Abundant
Hoplites	Rare	Common
Ancyloceras	Absent	Common
Crioceras	Absent	Common
Hamites	Abundant in one bed	Absent
Pachydiscus.......	Abundant in one bed	Absent
Schloenbachia	Abundant in Fredericksburg and Washita divisions. Several species	One species. Rare at top of Horsetown
Engonoceras and related Ammonites.............	Common	Absent
Turrilites	Locally abundant	Absent
Belemnites	Absent	Common

The comparisons could be carried further, showing many other genera that are found in only one of the areas, and that those occurring in both are not represented by closely related species.

The two faunas are complements of each other, and both must be taken together to make up a really representative Lower Cretaceous fauna. Their differences agree in a general way with those that exist between the northern and southern

European Cretaceous, but there are some variations, such as the occurrence of Lytoceras and Phylloceras with boreal forms in the Shasta and their absence from the southern Comanche where they belong.

As to the causes of the sharp contrasts between the Cretaceous faunas of the Texan region and the Pacific Coast, reasons based on the distribution of the fossil plants and on the geographic relations of the deposits have already been given for denying any considerable influence to climate, that is, difference in temperature. Dr. White has argued for the existence of a long, narrow, continental land barrier between the two areas of deposition, and that is doubtless the only single cause that seems at all adequate to explain the facts. But how far south the barrier extended and whether its position was constant we do not know. It is known that the Comanche fauna at one time extended almost to the present Pacific Coast in northern Sonora, and there is evidence that the Pacific fauna may have extended as far east as Catorce in San Luis Potosi, but whether the two seas were really connected or what their exact relations were we can only hope to learn when the details of Mexican geology are fully studied. Besides the existence of a barrier, the depth and clearness of the sea and the character of the bottom also probably had considerable influence. These conditions would at least explain the abundance of echinoids in one case and their absence in the other. The Shasta beds give every evidence of rapid deposition near shore in shallow waters, with usually a muddy bottom, while a large part of the Comanche series was laid down in deeper waters, or at least little influenced by clastic deposits derived directly from the land. One other factor has suggested itself, though it is probably not of much weight, and that is that the gregarious mollusks, like Aucella and the Ostreidæ, actually monopolized the sea bottom where either became well established, so that there was not room for both in the same area.

The study of these two incomplete faunas should emphasize the danger in depending on the statistical method in correlating

formations — the method in which each specific name is treated as a unit and the relative affinities of different deposits or localities are determined automatically by counting the number of common species. Here there are two great series of beds, each with a fairly large fauna, and not very far separated geographically, and yet if directly compared they show no identical and very few related species. Again, these conditions are suggestive when considering a sudden complete change in successive faunas, such as is often seen. If the barrier between the Comanche and Shasta seas had been suddenly removed and the succeeding conditions had been favorable for the continuation of only one of the faunas, we would have had in one of the areas such a complete and sudden change in faunas in two successive beds that a long time interval might have been erroneously invoked to explain it.

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TIMOTHY WILLIAM STANTON.

CORRELATION OF THE DEVONIAN FAUNAS IN SOUTHERN ILLINOIS.

INTRODUCTION.

THE Devonian faunas of the interior of America are of two distinct types, and occur in two more or less distinct geological provinces. The eastern interior province is typically represented in New York; it extends westward into Canada and southwestward into the Ohio valley. The western interior province is typically represented in Iowa; it extends to the northwest into British America and is connected with the European region. The southern Illinois Devonian is of much interest because of its geographic position between the New York and the Iowan areas, but in all the study which has hitherto been devoted to the region, it has never been definitely shown with which one of these provinces it is connected. Recent investigation shows the Devonian faunas in southern Illinois to be intimately related to the New York faunas, and that the strata containing them are but a western extension of the formations of the eastern province.

The "Devil's Back Bone" and the "Devil's Bake Oven," near Grand Tower, in Jackson county, Illinois, have long been recognized as localities rich in Devonian fossils. In 1855 Norwood and Pratten[1] described as new several species of *Chonetes* from this locality. In 1867 Hall made frequent mention, in Vol. IV of the Palæontology of New York, of the occurrence of species of brachiopods at the "Bake Oven," Jackson county, Illinois, and a few were described from this locality exclusively. In 1868 the geology of Jackson county was published in Vol. III of the Geological Survey of Illinois, several sketches of the "Bake Oven" and the "Back Bone" being reproduced and mention being made of the fossils collected. In the same volume are

[1] Jour. Acad. Nat. Sci., Phil., ser. 2, Vol. III, pp. 23–32.

descriptions and illustrations of several species of fossils from the locality.

The "Back Bone" is a narrow, rocky ridge, rising about one hundred feet above river level and extending northward from the town of Grand Tower along the east bank of the Mississippi River for a distance of about one-half mile. It consists of strata of Devonian limestone, with beds which are probably of Lower Helderberg age below, dipping to the northeast at an angle of about 25°. The "Bake Oven" is really the northern end of this ridge, but is isolated from the main "Back Bone" by an interval of several hundred feet.

The field work upon which the present paper is based was done in August 1896. As the time which could be devoted to the work was limited, it was concentrated upon the north face of the "Bake Oven." The section here studied is about 167 feet in thickness. An attempt was made to select the fossil-bearing zones in the section, and to make as complete collections from them as the time would allow. Twenty-six zones were recognized, eighteen of them being fossil-bearing to a greater or less extent. Additional time in the field would doubtless materially increase the number of species, and perhaps the number of zones, and a careful examination of the entire "Back Bone" would be exceedingly valuable.

DESCRIPTION OF THE SECTION, WITH LISTS OF FOSSILS.

The field number given to the section was *5A*. The beds, with their fossil contents, will be described, beginning with the lowest, $5A^{1}$ and passing upward through the successive zones to $5A^{26}$, which is the highest. The relative abundance of the species is designated as follows: (a) abundant, (c) common, (r) rare.

$5A^{1}$ About fifteen feet of coarsely crystalline, gray limestone exposed, variable in texture, and often more or less arenaceous, especially near the top. Fossils numerous but not well preserved.

1. *Leptæna rhomboidalis* Wilck. (c).
2. *Chonetes laticosta* Hall ? (r).

3. *Orthis* (*Rhipidomella*) *semele* Hall ? (a).
4. *Rhynchonella sp.* (r).
5. *Eatonia sp.* (r).
6. *Cyrtina hamiltonensis* Hall (r).
7. *Spirifer macrothyris* Hall (c).
8. *Spirifer raricostus* Conrad (c).
9. *Nucleospira elegans* Hall ? (r).
10. *Nucleospira ventricosa* Hall (r).
11. *Meristella sp.* (c).
12. *Platyceras sp.* (a).
13. *Orthoceras sp.* (r).
14. *Phacops cristata* Hall ? (r).
15. *Coral*, fragments (r).
16. *Bryozoa*, fragments (c).
17. *Fish teeth*, fragments (r).

5A[2] Two and one-half feet of rather coarse, light-colored sandstone. Fossils similar to those in the bed below, but poorly preserved.

1. *Leptæna rhomboidalis* Wilck. (c).
2. *Chonetes laticosta* Hall (r).
3. *Orthis* (*Rhipidomella*) *semele* Hall ? (c).
4. *Eatonia sp.* (r).
5. *Spirifer macrothyris* Hall ? (r).
6. *Spirifer sp.* (r).
7. *Nucleospira elegans* Hall ? ? (r).
8. *Platyceras sp.* (a).
9. *Dalmanites sp.* (r).

5A[3] Forty-five feet of impure, thin, irregularly bedded, dark limestone, variable in texture, and affording no fossils. Doubtless a more thorough examination of these beds would disclose a more or less abundant fauna.

5A[4] Six inches of impure, shaly limestone, lighter colored than that below and much decomposed upon the surface. Fossils poorly preserved.

1. *Pholidostrophia nacrea* Hall (r).
2. *Chonetes laticosta* Hall (r).
3. *Orthis* (*Rhipidomella*) *sp.* (c).
4. *Rhynchonella sp.* (r).
5. *Centronella glans-fagea* Hall (r).
6. *Spirifer duodenaria* Hall (c).
7. *Spirifer sp.* (r).
8. *Platyceras sp.* (r).
9. *Pleurotomaria* ? *sp.* (r).
10. *Phacops cristata* Hall ? (r).
11. *Bryozoa*, fragments (a).

5A[5]. Ten inches of dark brown, impure, limestone, with chert nodules.

1. *Productella spinulicosta* Hall (r).
2. *Dielasma ? sp.* (r).
3. *Spirifer grieri* Hall (r).
4. *Platyceras*, cf. young of *P. bucculentum* Hall (r).
5. *Phacops cristata* Hall *?* (r).
6. *Bryozoa*, fragments (a).

5A[6]. Four and one-half feet of unevenly bedded, partially crystalline, impure brown limestone.

1. *Strophodonta patersoni* Hall (c).
2. *Strophonella ampla* Hall (r).
3. *Chonetes mucronata* Hall (a).
4. *Orthis* (*Rhipidomella*) *vanuxemi* Hall *var?* (r).
5. *Orthis* (*Schizophoria*) *propinqua* Hall (a).
6. *Atrypa reticularis* Linn. (c).
7. *Cyrtina hamiltonensis* Hall (r).
8. *Spirifer grieri* Hall (r).
9. *Paracyclas elliptica* Hall (r).
10. *Platyceras sp.* (c).
11. *Lichas* (*chonolichas*) *eriopsis* Hall ? (r).
12. *Phacops cristata* Hall ? (r).
13. *Cystodictya sp.* (a).

5A[7]. Six feet four inches of thin, unevenly bedded gray-brown limestone nearly identical in lithological characters with the last.

1. *Strophodonta patersoni* Hall (c).
2. *Chonetes mucronata* Hall (a).
3. *Orthis* (*Rhipidomella*) *vanuxemi* Hall *var?* (c).
4. *Atrypa reticularis* Linn. (c).
5. *Spirifer varicosus* Hall (r).
6. *Nucleospira concinna* Hall ? (r).

5A[8]. One foot four inches of impure, semicrystalline, brown limestone with numerous fragments of corals too imperfectly preserved for identification.

5A[9]. Three feet of limestone similar to the last but without fossils.

5A[10]. One foot of limestone similar to the last.

1. *Strophodonta concava* Hall (r).
2. *Corals*, imperfect fragments (a).

5A[11]. Three feet ten inches of hard, brittle, semicrystalline, much fractured limestone, with an abundant fauna.

1. *Strophodonta patersoni* Hall (a).
2. *Strophodonta concava* Hall (a).
3. *Strophodonta perplana* Conrad (c).
4. *Strophodonta inequistriata* Conrad (c).

5. *Strophodonta demissa* Conrad (r).
6. *Pholidostrophia nacrea* Hall (r).
7. *Leptæna rhomboidalis* Wilck. (r).
8. *Orthothetes chemungensis* Conrad var. *arctostriata* Hall (r).
9. *Orthothetes chemungensis* Conrad var. *pandora* Billings (c).
10. *Chonetes mucronata* Hall (a).
11. *Productella spinulicosta* Hall (r).
12. *Orthis* (*Rhipidomella*) *vanuxemi* Hall *var.?* (a).
13. *Orthis* (*Schizophoria*) *propinqua* Hall (r).
14. *Rhynchonella louisvillensis* Nettelroth ? (r).
15. *Rhynchonella cf. horsfordi* Hall (r).
16. *Rhynchonella* (*Pugnax*) *sp.* (r).
17. *Atrypa reticularis* Linn. (a).
18. *Cyrtina hamiltonensis* Hall (a).
19. *Spirifer varicosus* Hall (a).
20. *Spirifer duodenaria* Hall (c).
21. *Nucleospira concinna* Hall (r).
22 *Paracyclas elliptica* Hall (r).
23. *Modiomorpha ? cf. M. recta* Hall (r).
24. *Grammysia cf. rhomboidalis* M. & W. (r).
25. *Conocardium cuneus* Conrad (c).
26. *Aviculopecten sp.* (a).
27. *Pterinea sp.* (r).
28. *Pterinea flabellum* Conrad ? (r).
29. *Platyceras bucculentum* Hall ? (c).
30. *Callonema lichas* Hall ? (c).
31. *Loxonema ? cf. L. pexatum* Hall ? (c).
32. *Bellerophon 2 sp.* (r).
33. *Lichas* (*Ceratolichas*) *cf. grypes* Hall (r).
34. *Dalmanites cf. calypso* Hall *cf. erina* Hall (c).
35. *Phacops cristata* Hall ? var. (r).
36. *Zaphrentis ?* imperfect fragments (c).
37. *Bryozoa* fragments (c).
38. *Fish Teeth* fragments (r).

5A[12]. Nine feet of impure, brown limestone with thin bands of chert. No fossils collected.

5A[13]. Five feet of limestone similar to the last.

1. *Strophodonta perplana* Conrad (c).
2. *Strophodonta demissa* Conrad (r).
3. *Strophodonta inequiradiata* Hall (c).
4. *Orthothetes chemungensis* Conrad *var. pandora* Billings (c).
5. *Chonetes mucronata* Hall (a).

6. *Productella Spinulicosta* Hall (r).
7. *Pentamerella cf. arata* Conrad (r).
8. *Rhynchonella sappho* Hall (r).
9. *Rhynchonella cf. horsfordi* Hall (r).
10. *Dielasma ? sp.* (r).
11. *Atrypa reticularis* Linn. (a).
12. *Spirifer sp.* (r).
13. *Paracyclas elliptica* Hall (r).
14. *Phacops cristata* Hall ? *var.* (r).
15. *Bryozoa*, fragments (a).

5A[14]. Twenty feet of impure brown limestone, variable in character and texture, thin bedded and shaly in part.

5A[15]. Five feet of impure reddish brown limestone.

1. *Strophodonta concava* Hall (a).
2. *Strophodonta demissa* Conrad (c).
3. *Leptæna rhomboidalis* Wilck. (a).
4. *Chonetes cf. deflecta* Hall (a).
5. *Orthis* (*Rhipidomella*) *vanuxemi* Hall (c).
6. *Paracyclas elliptica* Hall (r).
7. *Bellerophon sp.* (r).
8. *Gomphoceras lunatum* Hall ? (c).
9. *Gomphoceras impar* Hall ? (c).

5A[16]. Three feet ten inches of brown limestone.

1. *Strophodonta inequiradiata* Hall (r).
2. *Chonetes cf. deflecta* Hall (r).
3. *Orthis* (*Rhipidomella*) *vanuxemi* Hall ? var. (a).
4. *Orthis* (*Schizophoria*) *? sp.* (a).
5. *Spirifer sp.* (r).
6. *Paracyclas elliptica* Hall (r).

5A[17]. Five feet five inches of impure brown limestone. No fossils collected.

5A[18]. Three feet six inches of impure, reddish-brown limestone, composed almost wholly of a single species of *Chonetes*.

1. *Chonetes yandellana* Hall (a).
2. *Productella spinulicosta* Hall ? (r).
3. *Productella sp.* (r).
4. *Camarophoria sp.* (r).
5. *Dielasma cf. D ? navicella* Hall (r).
6. *Paracyclas elliptica* Hall (r).
7. *Platyceras sp.* (r).

5A[19]. Nine feet of impure brown limestone with few fossils.

5A[20]. Two feet impure shaly brown limestone with multitudes of a single species of *Chonetes.*

1. *Chonetes littoni* N. & P.? (a).
2. *Spirifer fornaculus* M. & W. (r).

5A[21]. Six feet of impure, thin bedded, brown limestone with few fossils.

5A[22]. Six inches impure brown limestone.

1. *Pholidostrophia nacrea* Hall (a).
2. *Productella spinulicosta* Hall (r).
3. *Dielasma sp.* (r).
4. *Atrypa reticularis* Linn. (r).
5. *Spirifer ziczac* Hall ? (a).
6. *Spirifer fornaculus* M. & W. (r).
7. *Favosites ? sp.* (r).

5A[23]. Three feet of dark, often nearly black, somewhat siliceous limestone with many fossils.

1. *Strophodonta inequiradiata* Hall (a).
2. *Strophodonta demissa* Conrad (c).
3. *Pholidostrophia nacrea* Hall (a).
4. *Leptæna rhomboidalis* Wilck. (a).
5. *Chonetes deflecta* Hall (a).
6. *Chonetes pusilla* Hall (a).
7. *Orthis (Schizophoria) iowensis* Hall (c).
8. *Spirifer fornaculus* M. & W. (c).
9. *Athyris vittata* Hall (c).
10. *Paracyclas elliptica* Hall (c).
11. *Paracyclas lirata* Conrad (r).
12. *Pleurotomaria sp.* (c).
13. *Bellerophon sp.* (r).
14. *Orthoceras sp.* (r).
15. *Phacops rana* Green (a).
16. *Proetus rowii* Green (r).
17. *Zaphrentis? sp.* (r).
18. *Cystodictya sp.* (a).

5A[24]. Nine feet of unexposed, covered at the time of examination with mud and water.

5A[25]. Three feet of dark brown impure limestone made up almost exclusively of specimens of *Chonetes coronata.*

1. *Chonetes coronata* Hall (a).
2. *Tropidoleptus carinatus* Conrad (a).
3. *Spirifer fornaculus* M. & W. (a).

4. *Bellerophon sp.* (r).
5. *Gyroceras cf. trivolve* Conrad (r).
6. *Tentaculites bellulus* Hall ? (c).
7. *Phacops rana* Green (c).
8. *Proetus canaliculatus* Hall (r).
9. *Zaphrentis sp.* (r).
10. *Cystodictya sp.* (c).

5A[26]. Four inches of impure brown limestone like the last, but with few specimens of *Chonetes coronata*.

1. *Orthothetes chemungensis* Conrad *var pandora* Billings (r) .
2. *Chonetes coronata* Hall (c).
3. *Spirifer fornaculus* M. & W. (a).
4. *Gomphoceras sp.* (r).

DISCUSSION OF THE FAUNAS.

From a general survey of the entire fauna of the section, seven conspicuous divisions may be recognized. The first of these include zones *5A*[1] and *5A*[2]. The conspicuous species are *Orthis* (*Rhiphidomella*) *semele?* and *Platyceras sp. Orthis* (*Rhipid.*) *semele* was originally described by Hall from very imperfect material found in the Onondaga limestone in Erie county, N. Y. The Illinois specimens are not perfectly preserved, but seem to agree more nearly with this species than with any other. The *Platyceras* is of a type which might be present in any fauna from the Lower Helderberg to the Hamilton inclusive. Well preserved specimens of *spirifer macrothyris* and *spirifer raricostus* are present, which are good Upper Helderberg species. Associated with these are *Nucleospira ventricosa* and *Nucleospira elegans?* which were described from the Lower Helderberg, and an undescribed species of *Eatonia*, which genus has not hitherto been recognized above the Oriskany. There is no fauna comparable to this one in the western interior Devonian province, but in the eastern province this association of species is about equivalent to the lower half of the Upper Helderberg group in the New York series.

The second division of the general fauna includes zones *5A*[4] to *5A*[13]. The association of species in these zones is a typical

Corniferous limestone fauna, as seen in Indiana, Ohio, and New York. The conspicuous species in the fauna are the large and robust *Strophodontas*, the *Atrypa reticularis* of the large, robust form so common at the falls of the Ohio, *Spirifer varicosus*, *Spirifer duodenaria*, *Orthis* (*Schizophoria*) *propinqua*, *Paracyclas elliptica*, *Conocardium cuneus*, *Lichas* (*Ceratolichas*) *cf. grypes*, *Dalmanites cf. calypso cf. erina*, etc. Nowhere in the western interior province does a fauna at all allied to this one occur, but it is identical with the Corniferous fauna of the eastern province.

The third division may be called the *Gomphoceras* zone, and includes only the bed numbered $5A^{15}$. It is characterized by numerous specimens of several large, robust species of *Gomphoceras*. The specimens as they occur on the surface of the outcrop are generally too imperfect for certain identification, but are of a general type of the genus which is common in both the Corniferous and the Hamilton faunas. The associated species are nearly all identical with those in the Corniferous fauna below.

The fourth division is the *Chonetes yandellana* zone, $5A^{18}$. The bed is made up almost exclusively of multitudes of specimens of this one species, all the others recorded being rare or uncommon.

The fifth division is the *Chonetes littoni?* zone, $5A^{20}$. It is similar to the *Chonetes yandellana* zone in being made up almost entirely of great numbers of individuals of a single species of *Chonetes*. *C. littoni*, with three other species of the same genus, was originally described from this locality by Norwood and Pratten, but their descriptions and figures are so imperfect that it is difficult to recognize their species. In the faunas of the section there are three conspicuous *Chonetes* zones, each containing exclusively a single species of the genus. Three of Norwood and Pratten's species, *C. maclurei*, *C. martini*, and *C. tuomyi*, may be certainly identified as different stages of a single species, *C. coronatus*, which characterizes the uppermost *Chonetes* zone. The chances are, therefore, that their fourth species, *C. littoni*, is

either one or the other of the two additional conspicuous species at the locality, and from careful examination and comparison of the specimens, descriptions and figures, it seems most probable that the species occurring in such numbers in zone $5A^{19}$ is the *C. littoni* of these authors.

The sixth division is zone $5A^{23}$, and has a fauna quite different from any of those below. *Leptæna rhomboidalis* is the most abundant species. Some of the additional conspicuous species are *Chonetes deflecta* and *Chonetes pusilla*, which are apparently variations of a single species, *Pholidastrophia nacrea*, *Athyris vittata* of the type common at the falls of the Ohio, *Phacops rana*, *Paracyclas elliptica* and *Paracyclas lirata*. As a whole the fauna is of a Hamilton facies, but is more like the Hamilton fauna at the falls of the Ohio than the typical New York fauna. *Orthis* (*Schizophoria*) *iowensis* is an uncommon species which is conspicuous in the Devonian faunas of Iowa, but is absent from the New York faunas until after the incursion of the Chemung faunas from the west.

The seventh and last division is zone $5A^{25}$, and may be termed the *Chonetes coronata* zone. The bed is made up of multitudes of individuals of *Chonetes coronata*, with perhaps one-tenth as many individuals of *Tropidoleptus carinatus*. Both of these species are peculiar forms and are characteristic of the New York Hamilton. They appear suddenly both in the New York and the Illinois localities without any known forerunners. *Tropidoleptus carinatus* is an abundant species in the South American Devonian faunas, and *Chonetes coronata* is of a type otherwise unknown in North America, but common in South America, where it is represented by *C. arcei Ulr.*, *C. rücki Ulr.*, and other species. There is evidence in the Hamilton fauna of the east-American province of an immigration from the southern hemisphere which did not affect the western Devonian faunas. The details of this epoch in Devonian history are not yet fully understood, but the presence of this *Chonetes coronata* and *Tropidoleptus* fauna marks the point where this immigration first made itself felt in the southern Illinois region.

CONCLUSION.

It is believed that the facts here set forth satisfactorily demonstrate that the Devonian faunas in southern Illinois are not related to the Iowan Devonian faunas as has sometimes been suggested, but are a western extension of the faunas of the New York province. At the "Bake Oven" section the fauna of the lowest beds is of an age corresponding to the lower portion of the Upper Helderberg period, while the uppermost faunas are of Hamilton age. The line of demarkation between the Upper Helderberg and Hamilton faunas cannot be exactly drawn, but it comes somewhere between zones $5A^{15}$ and $5A^{23}$.

In conclusion I wish to acknowledge the assistance given by Mr. A. W. Slocom, who has skillfully prepared the material for study.

Stuart Weller.

The University of Chicago.

EDITORIAL.

THE attendance at the Detroit meeting of the American Association for the Advancement of Science was notably smaller than usual, a result doubtless due in part to the meeting of the British Association at Toronto which followed at such an interval as to invite busy men to select the one at the expense of the other. The attendance upon the geological section was also adversely affected by the International Congress at St. Petersburg. The papers presented, however, were perhaps even more than usually important and interesting. The location of the meeting naturally invited an unusual number of papers relative to the problems of the Great Lake Basins and these easily took precedence. The widest popular interest was undoubtedly called forth by Mr. Gilbert's announcement of a definite tilting of the area of the lake basins towards the southwest. His deduction that the rate of change amounted to five inches per hundred miles per century, and his prophecy that at a specified date the drainage would be reversed, Niagara abandoned, and Detroit and Chicago flooded, naturally created something akin to a sensation in the great cities of the lakes. Incidentally this contribution to prophetic geology is having a good effect in removing the too wide impression that geology is a science of the ancient earth. The present and future belong to it as much as the past. The activity of recent years in current geomorphy is helping to awaken an appreciation of contemporaneous geology. A few decisive predictions will doubtless establish the value of prognostic geology.

This is not the first time that Mr. Gilbert has essayed the rôle of geological prophet, but it is, we believe, the first instance in which he has given us a definite time factor which holds out

the prospect that we may be able to bring him face to face with his responsibilities at a fixed day of fulfillment, though his dates are inconveniently distant. A prophecy which definitely courts a test of its accuracy by giving dates and amounts has a grateful moral flavor. The prospect of honor for fulfillment and punishment for failure is equitably distributed. Writing from this doomed locality we cannot lay claim to that indifference to results which is the prerequisite of complete impartiality in weighing the merits of the prophecy, but we have this comforting alternative that whatever the outcome we shall be able either to rejoice in the triumph of a friend or else join in the laugh of our neighbors at his failure.

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One of the features of especial interest at the Detroit meeting was the joint session of the anthropological and geological sections for the discussion of the relics of man found on the Delaware at Trenton, N. J., participated in by Putnam, Knapp, Kümmel, Wright, Holmes, Mercer, Wilson and Salisbury. Previous to the meeting all of these participants had visited the ground where excavation under the direction of Professor Putnam has been for some time in progress, and were thus armed with fresh facts from personal observation. The good influence of the "higher criticism" was manifest in the great care obviously taken in making and presenting the observations and in the critical and cautious attitudes assumed in their interpretation. The discussion was an altogether admirable one and formed an important episode in the progress of anthropic geology in this country. The discussion was essentially confined to the interpretation of a surface bed of sand three or four feet thick embracing scattered pebbles and irregular seams of ferruginous and silty materials, and of the artifacts found in it. This superficial bed rests upon the glacial gravels and lies on the brink of the terrace which overlooks the Delaware bottoms. The geological discussion centered upon the origin of this sandy deposit. The majority opinion and the weight of evidence seemed on the whole to favor a wind origin. No substantial evidence that it was of glacial or glacio-fluvial

origin, or that it was contemporaneous with any part of the ice age was presented. The anthropological discussion centered upon the question whether any civilization different from that of the early Algonkian Indians was shown by the relics. The former contention that the base of the deposit only carries argillite artifacts, while the upper carries quartz and jasper flakes also, was weakened by the reporting of a few jasper and quartz chips from the lower part. The hypothesis that the artifacts are palæolithic was weakened by the discovery of a small arrowhead in the heart of the deposit. On the whole the discussion seemed to leave the general impression that the evidence of any very ancient or very primitive form of civilization at this locality is of a quite slender and doubtful nature. The hypothesis of a glacial man was scarcely in serious discussion although incidentally alluded to, there being no proof that the beds are of glacial age. No new evidence of relics in the undoubted glacio-fluvial beds below was presented.

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At the Toronto meeting a similar joint session was held at which the broader subject of ancient man in America was discussed. The added point of interest there was the attitude of the British geologists and archæologists who are familiar with the character of the evidence in Europe where the antiquity of man is not seriously questioned. Their general disposition toward the evidence presented was that of marked conservatism. The foreign anthropologists and geologists seemed keenly alive to the inherent incongruities and self-destructive aspects of much of the supposed evidence for the great antiquity of man in America.

The influence of the two discussions will be very wholesome both within and without scientific circles.

The geological papers presented at the meeting of the British Association at Toronto were notable for the wide range of their themes and their high order of excellence. T. C. C.

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Papers offered at the Detroit meeting of the Geological Society of America, August 10, 1897:

"The Granite Mountain Area of Burnet County, Texas." By FREDERIC W. SIMONDS, Austin, Texas.

"Exposures near Detroit of Helderberg Limestone and Associated Gypsum, Salt and Sandstones." By W. H. SHERZER, Ypsilanti, Mich.

"Notes on the Geology of the Lower Peninsula of Michigan." By ALFRED C. LANE, Houghton, Mich.

"The Nomenclature of the Carboniferous Formations of Texas." By ROBERT T. HILL, Washington, D. C.

"Stratigraphy and Structure of the Puget Group, Washington." By BAILEY WILLIS, Washington, D. C.

"The Loess as a Land Deposit." By J. A. UDDEN, Rock Island, Ill.

"Ice-transported Bowlders in Coal Seams." By EDWARD ORTON, Columbus, O.

"Clay veins Vertically Intersecting Coal Measures." By W. S. GRESLEY, Erie, Pa.

"Analogy Between Declivities of Land and Submarine Valleys." By J. W. SPENCER, Washington, D. C.

"Great Changes of Level in Mexico and the Interoceanic Connections." By J. W. SPENCER, Washington, D. C.

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Papers offered at the Session of the Geological Section of the American Association for the Advancement of Science, Detroit, August 11-13, 1897:

Address of VICE-PRESIDENT WHITE. Subject: "The Pittsburg Coal Bed."

"The Geological Age and Fauna of the Huerfano Basin in Southern Colorado." By PROFESSOR HENRY F. OSBORN, Columbia University, New York, N. Y.

"An Account of the Researches relating to the Great Lakes." By DR. J. W. SPENCER, Washington, D. C.

"Lake Chicago and the Chicago Outlet." By FRANK LEVERETT, U. S. Geological Survey, Denmark, Ia.

"The Lower Abandoned Beaches of Southeastern Michigan." By FRANK B. TAYLOR, Fort Wayne, Ind.

"Some Features of the Recent Geology around Detroit." By FRANK B. TAYLOR, Fort Wayne, Ind.

"Recent Earth Movement in the Great Lake Region." By G. K. GILBERT, U. S. Geological Survey, Washington, D. C.

"Preglacial Topography and Drainage of Central-Western, New York." By PROFESSOR H. L. FAIRCHILD, University of Rochester, Rochester, N. Y.

"A Supplementary Hypothesis respecting the Origin of the American Loess." By PROFESSOR T. C. CHAMBERLIN, University of Chicago, Chicago, Ill.

"Progress of Hydrographic Investigations of the U. S. Geological Survey." By F. H. NEWELL, U. S. Geological Survey, Washington, D. C.

"Stylolites." By PROFESSOR T. C. HOPKINS, State College, Centre Co. Pa.

"A suggestion in regard to the Theory of Volcanoes." By PROFESSOR WILLIAM NORTH RICE, Wesleyan University, Middletown, Conn.

"The Ores and Minerals of Cripple Creek, Colorado." By H. P. PARMALEE, Charlevoix, Mich.

"Observations on the Genus Barrattia." By PROFESSOR R. P. WHITFIELD, American Museum Natural History, New York, N. Y.

"Ice Jams and what they Accomplish in Geology." By DR. M. A. VEEDER, Lyons, N. Y.

Reviews.

Geological Survey of Canada, Annual Report, Vol. VIII, 1895. By G. M. Dawson, Director, Ottawa, 1897.

This large volume embracing over a thousand pages contains a summary report of the work of the geological survey for the year 1896 by Director Dawson; "A report on the Country between Athabasca Lake and Churchill River" by J. Burr Tyrrell and D. B. Dowling; "A Report on the Geology of a Portion of the Laurentian Area lying to the North of the Island of Montreal," by Frank D. Adams, with appendices; "A Report on Explorations in the Labrador Peninsula along the East Main, Koksoak, Hamilton, Manicuagan and Portions of other Rivers in 1892–5," by A. P. Low, with biological, petrological and mineralogical appendices; "A Report of the Section of Chemistry and Mineralogy," by G. C. Hoffman; and of the "Section of Mineral Statistics and Mines," by E. D. Ingall. The report is accompanied by numerous maps and by photographic and other illustrations.

The summary by the director possesses the clearness and comprehensiveness which characterize all of Dr. Dawson's general papers. It gives an admirable synoptical review of the widely extended and varied enterprises of this great survey. The report of Mr. Tyrrell, and his assistant, Mr. Dowling, embraces observations made chiefly in the summer of 1892. They cover Recent, Pleistocene, Cretaceous, Keeweenawan, Huronian and Laurentian formations, besides topographic, biologic and other matters. The most important contributions are those which relate to the Athabasca sandstone, which appears to be the equivalent of the Keeweenawan of Lake Superior, to the Laurentian gneisses and associated formations, and to the Pleistocene deposits. These confirm and extend the previous well-known determinations of Mr. Tyrrell in the region west of Hudson Bay.

Dr. Adams' discussion of the crystalline rocks north of Montreal shows notable progress in the elucidation of the difficult problems of that region. Among the most important features are the advances made in the discrimination of original igneous gneisses from those of

metamorphic origin and the additional evidence of the degenerative granulation of the crystalline rocks as a result of great pressure.

The report of Mr. Low on his remarkable explorations in the Labrador peninsula contain a vast amount of new and important information respecting this heretofore *terra incognita*. It is impossible to satisfactorily summarize this. It shows that besides vast areas of gneisses and granitoid rocks presumably referable to the Laurentian series, there are extensive belts of later rocks of clastic origin referable to the Huronian and Cambrian series as interpreted by the Canadian survey. The rocks classified as Cambrian comprise beds of arkose rock, sandstone, chert, dolomite, felsitic shale, argillite and argillaceous shale, together with gabbro, diabase and fine-grained decomposed traps and volcanic conglomerates. They appear to embrace those debatable beds which are referred by some of the United States geologists to pre-Cambrian horizons. There is ground to hope that this extended area of these formations will afford the means for their complete elucidation. The observations of Mr. Low have made it clear that this great Labradorean area has a complex geological structure and is far from being properly characterized as simply Laurentian or even Archæan.

Mr. Low's contributions to glacial geology are very important. They show an outward movement in all directions from the center of the peninsula. He locates the central névé ground (which is characterized by only slight traces of glacial motion) midway between the east and west coasts of the peninsula, and between 53° and 55° latitude. Its southern boundary is in places from 150 to 200 miles north of the southern water-shed. The report is accompanied by "Notes on the Microscopical Structure of some of the Rocks of the Labrador Peninsula," by Mr. W. F. Ferrier.

The chemical, mineralogical and statistical reports embrace a large mass of valuable data. Altogether the report is one of the most important issued by the survey. T. C. C.

Iowa Geological Survey, Vol. VI. Report on Lead, Zinc, Artesian Wells, etc. SAMUEL CALVIN, State Geologist, A. G. LEONARD and H. F. BAIN, Assistant State Geologists. Des Moines, 1897.

This volume of 487 pages embraces reports on the "Lead and Zinc Deposits of Iowa," by A. G. Leonard; "The Sioux Quartzites and Cer-

tain Associated Rocks," by S. W. Beyer; "The Artesian Wells of Iowa," by W. H. Norton, and the "Relations of the Wisconsin and Kansan Drift Sheets in Central Iowa, and Related Phenomena," by H. Foster Bain.

Mr. Leonard describes the formations which embrace or are contiguous to the lead and zinc deposits, the mode of occurrence of these deposits, the association of the minerals and the particular forms of the ores. To these he adds special descriptions of the mines and a discussion of the origin of the deposits and the general methods of working them. He makes an important contribution to the general relationship of the ores in showing that in the Dubuque district zinc occurs in the higher horizons of the Galena limestone associated with the lead. This appears to require a modification of the generalization previously reached in Wisconsin and northwestern Illinois to the effect that the zinc usually occurs in lower horizons than the lead. The additional data appear to indicate that in their original deposition in the strata the zinc and lead were immediately associated with each other, and that their distribution in the crevices as the result of secondary action has been dependent upon the conditions of precipitation which were not uniform in all districts. Mr. Leonard regards the Archæan rocks as the original source of the lead and zinc, having been derived thence by surface decomposition and carried into the Silurian sea, from which in turn they were precipitated along with the gathering limestone. The precipitating agency he thinks was chiefly organic. He discusses the different theories of the localization of the metallic deposits, and concludes that on the whole Chamberlin's theory of oceanic currents offers the most plausible explanation. He regards the crevices as chiefly due to flexures of the strata aided by solution. He holds to the view that the minerals were carried into the crevices by lateral secretion from the surrounding limestones.

The rocks which Mr. Beyer finds associated with the Sioux quartzites embrace a series of slates and some olivine diabases. The slates he finds to conformably overlie the quartzite and to be somewhat interbedded with or graduated into the upper quartzitic layers. He regards the slates as an upward extension of the quartzite formation. In respect to the thickness of the quartzite formation he favors the lower estimate of Todd (1500 feet) rather than the higher estimate of Irving (3000 to 4000 feet), but regards both estimates as doubtful. He confirms the view of Irving that the quartzites were formed from siliceous

sandstones by interstitial growth. He favors the view that the quartzites are of early age, the probable equivalents of the Mankato and Baraboo quartzites.

Professor Norton introduces his discussion by a statement of the theory of artesian wells and their requisite conditions. He then describes the conditions of the Iowa field, discussing the geological structure, the area of supply, the reservoir and the conditions of transmission. This is followed by a description of the wells classified by sections. Under the head of chemistry of the waters he treats of the mineral ingredients, of the interpretation of analyses, and of the classification based on these; and also of the therapeutic, sanitary, and industrial qualities of the waters. He also touches upon the questions of public supply, of cost, of purity and of practical matters relative to drilling, thus giving to the report much popular as well as scientific interest.

The paper of Mr. Bain embraces a special study of the relations of the two drift sheets found in the vicinity of the capital. After a careful statement of the history of investigations, he describes, critically, the Des Moines lobe of the Wisconsin drift as it appears in Pope, Dallas, and Guthrie counties, and follows this by a similar critical discussion of the characteristics of the older drift which underlies it, and occupies the region lying to the south. An important feature of the paper is the discussion of time ratios as indicated by erosive and other phenomena. From the computation of special cases selected as being best suited to the purpose, he reaches the conclusion that the time ratio between the Wisconsin and the Kansan ranges from 1:10 to 1:15, being probably nearer the latter than the former.

The Iowa survey is to be congratulated upon the excellence of this report. T. C. C.

Geology and Natural Resources of Indiana; Twenty-first Annual Report. By W. S. Blatchley, State Geologist. Indianapolis, 1897.

This report of 718 pages embraces "An Introduction" and "The Natural Resources of Indiana," by W. S. Blatchley; "The Petroleum Industry in Indiana," by the same; "The Composition of Indiana Coals," by W. A. Noyes; "Some Notes on the Black Slate or Genessee Shale of New Albany," by Hans Duden; "The Indiana Caves and their Fauna," by W. S. Blatchley; "A Report on the Geology of the Middle

and Upper Silurian Rocks of Clark, Jefferson, Ripley, Jennings and Southern Decatur Counties," by August F. Foerste; "The Bedford Oölitic Limestone of Indiana," by T. C. Hopkins and C. E. Siebenthal; "The Report of the State Natural Gas Supervisor," by J. C. Leach; "The Report of the State Inspector of Mines," by Robert Fisher; "The Report of the State Supervisor of Oils," by C. F. Hall; "The Geology of Vigo County," by J. T. Scoville; and "A Catalogue of the Ferns and Flowering Plants of Vigo County," by W. S. Blatchley.

The paper of the state geologist on the petroleum industry of Indiana treats of the geographical and geological distribution of petroleum, of its origin, and the physical and chemical properties of the Indiana petroleum. He describes the oil fields by counties, introducing local details. The report closes with a chapter of a practical and economical character relating to the choosing of a locality for operating, the locating, drilling, and shooting of the wells, and their cost, accompanied by statistics with regard to the Indiana oil production.

Mr. Noyes gives the results of the twenty-seven analyses of coals, with an interpretation of results and a comparison of the coals.

The Notes on the Genessee Shale of New Albany, embrace chemical analyses, a statement of the previous experiments in utilizing the shale, and of new methods proposed by Mr. Duden, together with a discussion of the source of the bitumen embraced in the shales. The paper is accompanied by a description of some of the fossil plants discovered.

The discussion of the Indiana caves by the state geologist embraces descriptions of eighteen caves located in Owen, Monroe, Lawrence, Washington, and Crawford counties, accompanied by maps and photographic illustrations. This is supplemented by a description of the fauna of the caves, embracing mammals, batrachians, fishes, insects, and crustaceans, the descriptions being by W. S. Blatchley, J. M. Aldrich, Mary Murtfeldt, H. F. Wickham, and W. P. Hay.

In his discussion of the geology of the Middle and Upper Silurian rocks of the southeastern counties of Indiana, Dr. Foerste subdivides the formations for the purpose of more exact and refined study, as follows in descending order: The Niagara, into (1) the Louisville limestone or Utica lime rock, (2) the Waldron shale, (3) the Laurel limestone or Cliff rock, (4) the Osgood or cystidian beds, divided in places into (*a*) the Upper Osgood clay, (*b*) the Osgood limestone, (*c*) the Lower Osgood Clay. The Clinton group he does not subdivide.

The Cincinnati group he divides into (1) the Madison beds and their northern equivalents, (2) the richly fossiliferous shales and limestones below the Madison beds, (3) the Gastropod or Marvel Hill beds, and (4) a great section below not studied. The author enters into detail in the discussion of these formations and their special features in the more important localities, in the course of which the fossil contents receive special attention.

The discussion of the Bedford Oölitic limestone by Hopkins and Siebenthal is introduced by a discussion of the general geographical and stratigraphical features of the formation and associated strata. The body of the report embraces a discussion of the structural and economic features of the Bedford limestone, a discussion fully warranted by the very extensive use of the limestone as a building material. The treatment covers the results of both physical and chemical tests, and embraces the determination of the strength of the rock in various attitudes, its elasticity, absorption, resistance to fire and to water, its workability and accessibility. A chapter is devoted to the commercial features of the formation embracing the quarrying, handling of the stone, methods of work, machinery used, uses and adaptabilities of the stone, its transportation facilities, statistics of production, etc., which is followed by local descriptions. The discussion is closed by a classification of oölitic limestones.

The reports of the supervisors of gas, of mines, and of oil, embrace statistical and economic matter of value to those interested in these industries.

Dr. Scoville's "Geology of Vigo County" embraces the general topography and stratigraphy of the region, the ancient channels which cross the territory, but are now buried by the glacial deposits, the Pleistocene glacier of Vigo county, and the recent geology, embracing the soils and archæology.

The report has the same general form as preceding annual reports, but is more fully and better illustrated. T. C. C.

Geological Survey of Alabama, Eugene Allen Smith, State Geologist. Report on the Valley Regions. Part II, On the Coosa Valley. By Henry McCalley, Assistant State Geologist.

In this report the physical features of the Coosa Valley Region are classified into natural divisions, consisting of (1) broad, flat-topped

synclinal mountains bounded by bluffs; (2) uniform anticlinal valleys with sharp, well defined limits; (3) monoclinal mountains with steep northwest sides and gentle southeast slopes; (4) monoclinal valleys with ill-defined and irregular northwest limits; (5) flatwoods; (6) irregular valleys with jagged edges; and (7) chert hills and ridges. Each of these subdivisions is described and illustrated by local examples. The geology is introduced by brief reference to the changes due to denudation, after which the faults of the region, to the number of sixteen, are named and described. A general description of the geological formations of the region, ranging from the crystalline Talladega slates to the Lafayette, follows. The minerals, rocks, and other substances of special use and interest, are next discussed, and this is followed in turn by a chapter devoted to the soils, agricultural features, timber, water power, climate, health, and drainage of the region. The remainder of the report is occupied with county details, embracing Etowah, St. Clair, Jefferson, Tuscaloosa, Bibb, Shelby, Talladega, Calhoun, Cherokee, Clayborn, Coosa, and Chilton counties. The report is accompanied by maps and illustrated by excellent half tones.

The economic factor has a very prominent place throughout the report, and will doubtless render it very helpful in developing the important resources of the region. C.

First Report of the Geological Commission of the Colony of the Cape of Good Hope. Capetown, 1896.

The Geological Survey of the Colony of the Cape of Good Hope was recently organized by the appointment of Professor Corstorphine as geologist, and Arthur W. Rogers and Ernst H. L. Schwarz as assistant geologists. Considering the limitations of time, of means, and of personnel, this first report indicates an active prosecution of the work entrusted to the commission. The report in hand contains brief contributions on the following subjects: "Report on the Laingsburg Coal," by Professor Corstorphine; "Summary of the Work done in the Southwestern Districts," by Rogers; "Survey of the Beaufort West District," by Schwarz; "Summary of the Work done in the Tulbagh Area and Worcester District," by Schwarz; "Report of the Subcommittee on Deep Artesian Well Borings," by Stewart, Corstorphine, and Saunders; "Report of a Preliminary Geological Survey of

the Oudtshoorn and Prince Albert Districts made with a view to the Selection of a Site for a deep Borehole for Artesian Waters," by Corstorphine, and "The Cango Cave," by the same. Geologists will wish this new survey in a far-off land all possible success. C.

North Carolina and Its Resources. Issued by the State Board of Agriculture, Raleigh, 1896.

This is a general work intended to set forth the natural and cultural interests of the state. The subjects of geological interest are the topographic sketches illustrated by half tones, the climatic statistics, a geological map, a list of native minerals, a sketch of the gold, silver, copper, iron, corundum, mica, talc, monazite, marl, phosphate, coal, graphite, kaolin, and clay industries, and of the gems and gem stones of the state. The building stones and road material are also briefly treated. The work is well illustrated with excellent half tones, and is a very creditable book. C.

Bulletin of the Minnesota Academy of Natural Sciences, Vol. IV, No. 1, Part I. *Proceedings and Accompanying Papers 1892 to 1894.* By C. W. Hall, Editor. Minneapolis, 1896.

The papers of geological interest are: "Notes on the Alpine Characteristics of the Minnesota Flora of the Coteau des Prairies," by E. P. Sheldon; "The St. Peter's Sandstone," embracing descriptions of its fauna, including fourteen genera and twenty-eight species, and a discussion of its origin and correlation, by F. W. Sardeson; and "The Fauna of the Magnesian Series with Descriptions of its Fossils," by F. W. Sardeson. The large additions to the fauna of the Magnesian and St. Peter's horizons gives special value to these two papers. C.

Proceedings of the Iowa Academy of Sciences for 1896. Vol. IV, Des Moines, 1897.

The volume contains a portrait of the late Charles Wachsmuth, accompanied by a memorial by Dr. Charles R. Keyes. The papers of geological interest are "The State Quarry Limestone," by Samuel Calvin; "Stages of the Des Moines, or Chief Coal-Bearing Series of

Kansas and Southwest Missouri and their Equivalents in Iowa," by Charles R. Keyes; "The Vertical Range of Fossils at Louisiana," embracing an extended table, by Charles R. Keyes and R. R. Rowley; "Natural Gas in the Drift of Iowa," by A. G. Leonard; "The Results of Recent Geological Work in Madison County," by J. L. Tilton; "The Drift Section at Oelwein," by Grant E. Finch; "Evidence of a Sub-Aftonian Till Sheet in Northeastern Iowa," illustrated by a section and three full page half tones, by S. W. Beyer; "A Pre-Kansan Peat Bed," by T. H. MacBride; "A Summary of the Discussion of the Preceding Papers on the Oelwein Section," by Professor S. Calvin; and "Additional Observations on Surface Deposits in Iowa," by B. Shimek. The remaining papers are chiefly biological.

Proceedings of the Davenport Academy of Natural Sciences, Vol. VI, 1889 to 1897. Davenport, 1897.

In this volume of 400 pages the archæological contributions very notably predominate. Some of these, however, possess geological interest from their connection with recent deposits. The dignity of the volume and of the society is lowered by an endorsement of the ridiculous claims of Captain Glazier, which are unworthy of serious consideration.

Stone Implements of the Potomac-Chesapeake Tidewater Province. By WILLIAM H. HOLMES. From *Fifteenth Annual Report of the Bureau of Ethnology.* J. W. POWELL, Director. Washington, D. C., 1897.

This paper, though primarily archæological, possesses much geological interest because of its bearing upon anthropic geology. It consists of an elaborate discussion of the manufacturing of flaked stone implements and of the ancient quarry workshops of the District of Columbia, in which this manufacture was extensively carried on. The geological relations of these quarries and of the terranes in which they occur are accurately and fully set forth by sections, photographs, and sketches of the clearest possible type. The various stages of manufacture are fully elucidated by drawings and photographs, so that every feature of the process is most completely and convincingly elucidated. The conclusions reached by Professor Holmes are already

familiar to the readers of this magazine. The results of his prolonged investigations are here brought together, summed up and illustrated with a beauty and force which make the paper a monumental contribution to archæology and anthropic geology. C.

Glacial Observations in the Umanak District, Greenland. By PROFESSOR GEORGE H. BARTON. *Report B of the Scientific Work of the Boston Party on the Sixth Peary Expedition to Greenland.*

The paper embraces the observations made by Professor Barton on the border of the inland ice in the vicinity of Umanak fiord and upon the large Karajak, Itivdliarsuk and several small valley glaciers. Mr. Barton found the border of the ice usually nearly vertical to the height of ten to forty feet. The surface in the vicinity of the margin was covered with dust holes ranging in diameter from a fraction of an inch up to at least three feet, with an average depth of about two feet. Except the dust found in these holes no detritus occurs on the surface of the inland ice. The largest surface stream found flowed in a channel having a width of twenty feet with a depth of fifteen feet to the surface of the water which was about five feet in depth. At the point observed this river was flowing directly toward the interior with a velocity of three or four miles an hour. The average gradient of the surface measured on the Karajak glacier was found to be 1 in 52. Professor Barton observed that the overhanging marginal faces were in many cases apparently due to a shearing motion of the upper layers over the lower. "This was indicated quite strongly in one instance, where a layer projecting slightly beyond the ones above had caught a little detritus as it rolled down. This same ledge continued from the slightly inclined face along a portion of the overhanging face, and here still the detritus remained which had been caught in its descent before the shearing motion had changed this part of the face to an overhanging one. A cavern presented a chance for a study of the material forming the layer upon which the detritus had lodged, and also for several feet above, showing them to be free from detritus and consequently that the detritus could only have come from the upper surface and caught upon the shelf, while the face was inclined, and that its present overhanging form was due to the shearing motion in the upper portion of the ice"—a very important observation.

Professor Barton gives interesting illustrations of the hold of the

ice upon bowlders, and of its methods of behavior in passing over projecting knobs of rock. He also gives an instructive diagram of the method of discharge of the ice foot where it protrudes into the water. Professor Barton believes that the ice "once extended over all this portion of Greenland, passing out beyond the farthest limits of the present coast line into the open waters of Baffin's Bay." He is not altogether fortunate in his suggestions with reference to Dalrymple Rock, a figure of which he introduces for comparison, with the suggestion that it "presents a marked stoss and lee side, apparently in their appropriate positions as related to the mainland topography seen in the distance." The apparent stoss side faces Baffin's Bay and not the inland ice. There is a radical difference between Dalrymple Rock and the peaks of Ikerasak and of Umanak Island, with which it is put in comparison, in the fact that the pedestals of the two latter are distinctly glaciated, showing that they have been typical nunataks, while the base of Dalrymple Rock shows no signs of glaciation and belongs in an entirely different category.

The paper is admirably illustrated with half tone photographs.

T. C. C.

Seventeenth Annual Report of the United States Geological Survey Part I, Director's Report and other papers; Part II, Economic Geology and Hydrography; Part III, Mineral Resources of the United States. CHARLES D. WALCOTT, Director, Washington, D. C., 1896.

This voluminous report embracing three thousand pages of matter which has just come to hand can only be briefly noticed here. It is hoped that special reviews of its important papers may be given hereafter. The report opens with the usual statement of the operations of the survey by the Director. It includes the work done in the years 1895–6 by the nearly forty parties in geology and palæontology, by the divisions of chemistry and hydrography, by the statisticians, and by the topographic and publication branches. This is followed in Part I by papers on "The Magnetic Declination in the United States," by Henry Gannett; "A Geological Reconnaissance in Northwestern Oregon," by J. S. Diller; "Further Contributions to the Geology of the Sierra Nevada," by H.W. Turner; "A Report on the Coal and Lignite of Alaska," by W. H. Dall; "The Uintaite (Gilsonite) Deposits of Utah,"

by G. H. Eldridge; "The Glacial Brick Clays of Rhode Island and Southeastern Massachusetts," by N. S. Shaler, J. B. Woodworth and C. F. Marbut; and "The Faunal Relations of the Eocene and Upper Cretaceous on the Pacific Coast," by T. W. Stanton.

Part II embraces "The Gold-Quartz Veins of Nevada City and Grass Valley, California," by Waldemar Lindgren; "The Geology of Silver Cliff and the Rosita Hills, Colorado," by Whitman Cross; "The Mines of Custer County, Colorado," by S. F. Emmons; "A Geological Section Along the New and Kanawha Rivers in West Virginia," by M. R. Campbell and W. C. Mendenhall; "The Tennessee Phosphates," by C. W. Hayes; "The Underground Water in the Arkansas Valley in Eastern Colorado," by G. K. Gilbert; "A Preliminary Report on the Artesian Waters of a Portion of the Dakotas," by N. H. Darton; and "The Water Resources of Illinois," by Frank Leverett, accompanied by an account of the "Palæozoic Rocks Explored by Deep Borings at Rock Island, Ill.," by J. A. Udden.

Part III embraces the "Report on the Mineral Resources of the United States for 1895," by Dr. David T. Day and associates. This includes reports on The Iron Ores, by John Birkinbine; on The Present Condition of the Iron and Steel Industries of the United States, by James M. Swank; on Copper, Lead and Zinc, by Charles Kirchoff; on Chromic Iron, by William Glenn; on Antimony, Coal, Asphaltum, Soapstone, Abrasive Materials, Sulphur and Pyrites, Gypsum, Salt, Asbestos. Mineral Paints and Barytes, by Edward W. Parker; on Manganese, Coke, Petroleum and Natural Gas, by Joseph D. Weeks; on Stone, by William C. Day; on Clay, by Jefferson Middleton; on Pottery, by Heinrich Reis; on Portland Cement, by Spencer B. Newberry; on American Rock Cement, by Uriah Cummings; on Precious Stones, by George F. Kunz; on Mineral Waters, by Alfred C. Peale; and on Gold, Quicksilver, Tin, Aluminium, Nickel, Cobalt, Platinum, Phosphate Rock, Fluorspar, Chryolite, Mica and Graphite, by the chief of the division.

Altogether the list of papers is one of unusual range and importance.

C.

THE

JOURNAL OF GEOLOGY

OCTOBER–NOVEMBER, 1897

A GROUP OF HYPOTHESES BEARING ON CLIMATIC CHANGES.[1]

WHILE the atmosphere is the most active of all geological agencies, it has received the least careful study from geologists. Its very activity destroys its relics almost as soon as formed and gives them peculiar evanescence. This has invited the neglect of geologists laudably prone to concentrate their attention upon agencies which have left enduring and unequivocal records. The atmospheric element in geological history bids fair to long remain obscured by elusive factors and uncertain interpretations. None the less it is an element of supreme importance and should be persistently attacked until it yields up its truths. This must be my excuse for offering a paper which, I am painfully aware, is very speculative in many of its parts.

All our attempts at the solution of climatic problems proceed on some conscious or *unconscious* assumption concerning the extent and nature of the atmosphere at the stage involved. These assumptions are too often unconscious and the conclusions reached command a confidence which might not be reposed in them if the underlying assumptions were frankly stated. It may not be unwholesome, therefore, to raise some radical doubts respecting current assumptions regarding the early stages of the

[1] Read before the British Association for the Advancement of Science at Toronto, August 20, 1897. For obvious reasons it was necessary to treat the many factors involved with extreme brevity and hence with some obscurity and much lack of adequate qualification. I have taken the liberty of adding some tables and other matter

atmosphere and to offer for trial a competitive hypothesis or group of hypotheses. To admit a competitive hypothesis to the working list is a concrete form of embodying a doubt respecting existing hypotheses and serves better than any abstract skepticism to keep alive the sources of doubt. I assume that the system of multiple working hypotheses is accepted as furnishing the most wholesome conditions for research, and that any additional hypothesis not in itself incredible will be welcomed.

If we compute the mass of the several constituents of the present atmosphere, and estimate the rate at which they are being consumed in alterations of the superficial rocks, we find that the carbon dioxide will last but a short period unless there be some source of supply. A group of careful estimates by different methods gives results ranging from five thousand to eighteen thousand years[1] with a weighted mean of about ten thousand years. Only the alteration of the crystalline terranes was admitted to the computations. The estimates assumed the degradation rates of current geological opinion. Granting these may be too high, and multiplying the results accordingly, it still appears that we are confronted by the early exhaustion of a vital factor of the atmosphere, if there be no compensating source of supply.

There is, however, an immediate source of compensation. The ocean is an atmosphere in storage. It is not improbable

and of slightly extending and modifying the treatment on some points, but it still remains merely synoptic. The treatment of the periodicity of Pleistocene atmospheric changes is especially incomplete, but this is only a particular case under a general hypothesis whose value does not necessarily hang upon this individual application.

I desire to add that most of the questions involved in the paper have been discussed with scientific friends and with the advanced graduate students of my classes during the past two years, and that I have received from them much valuable aid. Computations and quantitative estimates have been made by F. R. Moulton, H. L. Clarke, A. W. Whitney, J. P. Goode, H. F. Bain, Samuel Weidman, C. F. Tolman, Jr., N. M. Fenneman, and C. E. Siebenthal, which I desire to gratefully acknowledge. The main points of the paper were presented to the Geological Club of the University of Chicago, October 1896.

[1] Made by A. W. Whitney, H. Foster Bain, J. P. Goode, Samuel Weidman, C. F. Tolman, Jr., and the writer.

that every portion of it has once been a constituent of the atmosphere and may be again. In atmospheric studies it must be recognized as a potential atmosphere. According to the best data at command, the ocean holds in solution about eighteen times as much carbon dioxide as the atmosphere. But even this reserve supply if fully available leaves the perpetuity of atmospheric conditions congenial to life very short, viewed geologically. This threat of disaster is not, however, a scientific argument, whatever function it may have in awakening interest and neutralizing inherited prejudice.

A broad comparison between the atmosphere of Palæozoic times and that of Cenozoic times fails, I think, to give proof of any radical difference in the constitution of the two atmospheres. The magnolia flora in North Greenland in Tertiary times indicates a scarcely less wide distribution of warm climate than the life of the same region in Palæozoic times. Glaciation in northern Norway announced by Reusch and confirmed by Strahan, in times apparently just preceding the Palæozoic era, is as suggestive of atmospheric poverty as anything that introduces the Cenozoic times. The signs of glaciation at the close of the Palæozoic era in India, Australia, and South Africa, reaching within 20° of the equator, indicate a thermal depression even more marvelous than that which closed the Cenozoic era. The salt deposits of the middle latitudes in Palæozoic times, notably those of Michigan and New York, in areas where the great basins now overflow voluminously, seem to imply an aridity quite comparable to anything which has succeeded. The extensive terranes of hematite-stained rocks, contrasted with the limonite-stained terranes, while their interpretation is more problematic, make suggestions of concurrent import.

A comparison of early with later life, stripped of theoretical presumptions, does not seem to me clearly to imply any great difference in the content of carbon dioxide. Air-breathing life, to be sure, has left no certain record earlier than the middle Palæozoic, but these earliest forms afford no clear proof that they were determined by non-susceptibility to an excess of carbon

dioxide. The delay in the appearance of land life is sufficiently assignable to the obstacles to its evolution to make needless a theoretical appeal to a noxious condition of the atmosphere.

But if we compute the amount of carbon which has been extracted from the atmosphere in the production of the carbonates and the carbonaceous deposits, and restore this to the atmosphere, following a time-honored custom, we are led to the time-honored conception of an exceedingly extensive, dense, warm and moist atmosphere. The amount of carbon dioxide represented by the limestones and carbonaceous deposits has been variously estimated at twelve thousand to one hundred and fifty thousand times the present content of the atmosphere. My own estimates lead me to favor figures lying between twenty thousand and thirty thousand. These estimates do not go back of the Palæozoic series and leave an unknown factor to be added for the pre-Cambrian limestones and carbonaceous deposits. The amount of carbon extracted from the atmosphere since the introduction of air-breathing life is probably not less than 8000 or 10,000 times the amount now in the air. This forces the question whether this large amount of carbon dioxide or any major part of it was ever in the atmosphere at any one time.

The alternative is to assume that the atmosphere was originally less ample and has been fed as well as robbed during all the geological ages, its history being a struggle between enrichment and depletion. In some measure this is an accepted view, but it is part of the purpose of this paper to show that the way is open to freer hypothesis in this direction.

The current view of a vast original atmosphere is derived less perhaps from the computation of material extracted from it than from theoretical views regarding the origin and early history of the earth. There has been quite general assent to the nebular theory of the origin of the earth. Even where dissent from the gaseous features of this theory has been entertained there has been acquiescence in the doctrine of the earth's early molten condition and all that it implies. If the earth were in a thoroughly molten condition, there would seem at first thought but

scant ground for any dissent from the inference that the present hydrosphere was then mainly a part of the atmosphere. It does not rigorously follow, however, that this was so. Hypothesis may go so far as to attribute much of the subsequent ocean and atmosphere to vapors thrown out of the molten magma as it cooled and to vapors gathered from space since. But I venture to question the supposed original molten state. While making no claim to disprove it, I doubt whether it rests on sufficiently solid theoretical grounds to justify the assumptions so unhesitatingly built upon it. There is still some ground to doubt the nebular hypothesis and to entertain some of the various phases of the meteoroidal hypotheses. The nebular hypothesis correlates a wonderful array of remarkable facts and has gained a profound hold upon the convictions of the scientific world, yet some of its great pillars of support have recently weakened or have fallen away entirely. Of the 5000 known nebulæ to which we naturally look for analogy very few, if indeed any, strictly interpreted, exemplify in a clear and decisive manner the systematic annular evolution postulated by Laplace. The photographs of the nebula of Andromeda, that were hailed with such delight on their first appearance as exemplifying the Laplacean hypothesis, appear upon more critical study to support it only in vague and general terms, if indeed they lend it support at all. The Saturnian rings, the trite source of illustration and analogy, prove under the test of the spectroscope to be formed of discrete solid particles, and not of gas, and the investigations of Roche have put a new phase on their theory. While in their form they tally with the annular hypothesis they do not support its gaseous phase, if indeed they lend it any support at all. But our chief interest is not in the general theory, but in the special inferences drawn from it respecting the early stages of the earth. Let us assume the possible or, if you please, probable truthfulness of the nebular hypothesis so far as the separation of an earth-moon ring from the shrinking sun is concerned. Do the subsequent steps commonly postulated logically follow?

The vast radiating surface of such a ring, its attenuated

nature and the extremely high temperature necessary to maintain its refractory substances in a volatile condition combine to suggest its speedy passage from the vaporous to the Saturnian or discrete solid condition from loss of heat. It seems a severe tax upon probabilities to suppose that such a ring would remain in the gaseous condition during the long period of its aggregation into a spheroidal form.

But a graver source of doubt is found in the high molecular velocities of the gases under these conditions. Dr. Johnstone Stoney[1] and others have attempted to show that the attractive power of small planets is insufficient to control gases of the higher molecular velocities, especially aqueous vapor. To this is attributed the measurable absence of atmospheres on the satellites and small planets. An endeavor to apply a similar line of reasoning to the conditions of the early earth leads to such disquieting results that I may be justified in briefly sketching it.

Each celestial body has an attractive power sufficient to control molecules shot away from it at velocities below a certain limit. At these velocities the discharged molecules pursue elliptical paths and return to the starting point. At the limit of these velocities they pursue parabolic courses and never return. Hence arises the expression "parabolic velocity" to indicate the limital speed at which particles shot away from the body will not return. The parabolic velocity of the earth at its surface is about 6.9 miles (1118127^{cm}) per second. A molecule discharged from it at that speed or a greater one will not return to it. The parabolic velocity is but an expression of effective gravity and

[1] "On the Cause of the Absence of Hydrogen from the Earth's Atmosphere and of Air and Water from the Moon." Royal Dublin Society, 1892. Since this paper was put in type I have been permitted to see an advanced copy of Dr. Stoney's later paper, "Of Atmospheres upon Planets and Satellites," Trans. Royal Dublin Society, Vol. VI, Part 13, Oct. 25, 1897, in which the author's investigations are much more fully set forth and his conclusions greatly strengthened. He takes account of the rotary speed of the outer equatorial zone and of westerly winds as projectile aids, factors which are neglected in this discussion. He also bases a very strong argument on the absence of helium from the present atmosphere, which on account of its chemical inertness would accumulate if it were not discharged.

depends not only upon the amount of the material embraced in the body, but on its distribution and other conditions. The parabolic velocity declines with height, as shown in the following table prepared for me by Mr. F. R. Moulton.[1]

I.

TABLE OF THE EARTH'S PARABOLIC VELOCITIES (V_p') FOR VARIOUS HEIGHTS ABOVE ITS CENTER (X) THE EFFECTS OF ROTATION BEING NEGLECTED.*

When x (height above center) = 0	$V_p' = +\infty$	
When x = r (earth's radius)	V_p' = 11181.3	meters
When x = 7×10^6 meters	V_p' = 10672.5	"
When x = 8×10^6 "	V_p' = 9983.2	"
When x = 9×10^6 "	V_p' = 9412.2	"
When x = 10^7 "	V_p' = 8914.1	"
When x = 12×10^6 "	V_p' = 8151.2	"
When x = 14×10^6 "	V_p' = 7546.6	"
When x = 17×10^6 "	V_p' = 6848.4	"
When x = 20×10^6 "	V_p' = 6313.9	"
When x = 25×10^6 "	V_p' = 5647.3	"
When x = 30×10^6 "	V_p' = 5155.3	"
When x = 40×10^6 "	V_p' = 4464.6	"
When x = 60×10^6 "	V_p' = 3645.3	"
When x = 10^8 "	V_p' = 2823.7	"
When x = 15×10^7 "	V_p' = 2305.5	"
When x = 5×10^8 "	V_p' = 1262.8	"
When x = 25×10^8 "	V_p' = 564.7	"

* $V_p' = \frac{\sqrt{2gr^2}}{\sqrt{x}}$ Log. $2g = 1.2923447$.

$2g = 64.32$ ft. $= 19.604$ meters. Log. $r^2 = 13.6092842$.

$r = 6{,}377{,}377$ meters. Log. $\sqrt{2gr^2} = 7.4508144$.

The parabolic velocity is also reduced by the centrifugal component of rotation. The effect of this is shown in the following tables computed by Mr. Moulton:

[1] Assistant in Astronomy at the University of Chicago.

II.

TABLE OF PARABOLIC VELOCITIES OF THE EARTH (V_p') FOR VARIOUS HEIGHTS ABOVE ITS CENTER (X) WHEN THE PERIOD OF ROTATION IS 23 HOURS, 56.067 MINUTES.*

When x (height above center) $= 0$			$V_p' = + \infty$
When $x = r$ (earth's radius)			$V_p' = 11181.27$ meters
When $x =$	7×10^6 meters	(4,349 miles)	$V_p' = 10672.49$ "
When $x =$	8×10^6 "	(4,972 ")	$V_p' = 9983.16$ "
When $x =$	9×10^6 "	(5,593 ")	$V_p' = 9412.15$ "
When $x =$	10×10^6 "	(6,214 ")	$V_p' = 8914.05$ "
When $x =$	12×10^6 "	(7,457 ")	$V_p' = 8151.14$ "
When $x =$	14×10^6 "	(10,700 ")	$V_p' = 7546.52$ "
When $x =$	17×10^6 "	(10,564 ")	$V_p' = 6848.31$ "
When $x =$	20×10^6 "	(12,428 ")	$V_p' = 6313.79$ "
When $x =$	25×10^6 "	(15,544 ")	$V_p' = 5647.17$ "
When $x =$	30×10^6 "	(18,643 ")	$V_p' = 5155.14$ "
When $x =$	40×10^6 "	(24,857 ")	$V_p' = 4464.39$ "
When $x =$	60×10^6 "	(37,286 ")	$V_p' = 3644.98$ "
When $x =$	100×10^6 "	(62,144 ")	$V_p' = 2823.17$ "
When $x =$	150×10^6 "	(93,216 ")	$V_p' = 2304.70$ "
When $x =$	500×10^6 "	(310,720 ")	$V_p' = 1260.14$ "
When $x =$	2500×10^6 "	(1,553,600 ")	$V_p' = 551.40$ "
When $x =$	10000×10^6 "	(6,214,400 ")	$V_p' = 229.19$ "
When $x =$	30434×10^6 "	(18,902,905 ")	$V_p' = .00$ "

$$*V_p' = \frac{\sqrt{2gr^2}}{\sqrt{x}} - \frac{4\pi^2 x}{t^2} \qquad t = 23^h \ 56.067^m = 86164^s.$$

$$\text{Log. } \sqrt{2gr^2} = 7.4508144. \qquad \text{Log. } \frac{4\pi^2}{t^2} = \bar{9}.7257080.$$

III.

TABLE OF PARABOLIC VELOCITIES OF THE EARTH (V_p') FOR VARIOUS HEIGHTS ABOVE ITS CENTER WHEN THE ROTATION PERIOD IS 1 HOUR, 24 MINUTES, AT WHICH THE CENTRIFUGAL COMPONENT OF ROTATION EQUALS THE ACCELERATION OF GRAVITY AT THE EQUATORIAL SURFACE.*

When x (height above center) $= 0$		$V_p' = + \infty$
When $x = r$ (earth's radius)		$V_p' = 11171.39$ meters
When $x =$	7×10^6 meters	$V_p' = 10661.69$ "
When $x =$	8×10^6 "	$V_p' = 9970.8$ "
When $x =$	9×10^6 "	$V_p' = 9398.2$ "

III—*continued.*

When $x = 10 \times 10^6$	"	$V_p' =$ 8898,5	"
When $x = 12 \times 10^6$	"	$V_p' =$ 8132.5	"
When $x = 14 \times 10^6$	"	$V_p' =$ 7524.8	"
When $x = 17 \times 10^6$	"	$V_p' =$ 6822.0	"
When $x = 20 \times 10^6$	"	$V_p' =$ 6282.8	"
When $x = 25 \times 10^6$	"	$V_p' =$ 5608.4	"
When $x = 30 \times 10^6$	"	$V_p' =$ 5108.7	"
When $x = 40 \times 10^6$	"	$V_p' =$ 4402.4	"
When $x = 60 \times 10^6$	"	$V_p' =$ 3552.0	"
When $x = 100 \times 10^6$	"	$V_p' =$ 2668.3	"
When $x = 150 \times 10^6$	"	$V_p' =$ 2072.4	"
When $x = 500 \times 10^6$	"	$V_p' =$ 485.7	"
When $x = 691 \times 10^6$	"	$V_p' =$ .0	"

$$*V_p = \frac{\sqrt{2gr^2}}{\sqrt{x}} - \frac{4\pi^2 x}{t^2} \qquad \text{Log. } \sqrt{2gr^2} = 7.4508144$$

$$t = 1^h \quad 24^m = 5040^s \qquad \text{Log. } \frac{4\pi^2}{t^2} = \bar{6}.1914987$$

The molecular velocities vary with temperature. The following table computed for me by Mr. A. W. Whitney exhibits these velocities for temperatures ranging from zero to 4000° C.:

IV.

TABLE OF AVERAGE MOLECULAR VELOCITIES FOR VARYING TEMPERATURES, IN CENTIMETERS PER SECOND, STANDARD PRESSURE.

	0°	100°	1000°	1250°	1500°	2000°	3000°	4000°
H_2	169611	198257	367258	400428	432243	489410	587282	671029
H_2O	56522	66067	122054	133501	144042	163093	195707	223619
CO_2	33259	38876	71819	78556	84759	95965	115160	131580
O_2	39155	45768	84551	92482	99786	112983	135576	154907
N_2	41735	48784	90122	98574	106359	120425	144508	165115

The molecules of a gas of a given temperature have a mean velocity, but this does not express the actual velocity of the individual molecules. By their interaction upon one another the velocities of some are depressed, the limit being zero, and the velocities of others are increased, the limit being infinity.

Theoretically both these limits may be reached, but extremely high velocities are acquired at such distant intervals as to be negligible. Very considerable exaltations of velocity are however attained with sufficient frequency to be effective in discharging a large part of the gas under suitable conditions, since each molecule in succession is liable to acquire a high velocity. The following table shows the proportion of molecules that reach or exceed the designated multiples of the average velocity at any instant:[1]

V.

TABLE SHOWING THE PROPORTION OF MOLECULES WHICH HAVE A GIVEN NUMBER OF TIMES THE AVERAGE 0° C. VELOCITY (OR MORE) AT ANY INSTANT, STANDARD PRESSURE, FOR TEMPERATURES RANGING FROM 0° C. TO 4000° C.

Proportion of Molecules	Times Average 0° C. Velocity for different Temperatures					
	t = 0° C.	t = 1000° C.	t = 1500° C.	t = 2000° C.	t = 3000° C.	t = 4000° C.
4.7×10^{-1}	1	2.2	2.5	2.9	3.5	3.9
1.7×10^{-2}	2	4.3	5.1	5.8	6.9	7.9
4.2×10^{-5}	3	6.5	7.6	8.7	10.4	11.9
7.4×10^{-9}	4	8.6	10.2	11.5	13.9	15.8
9.7×10^{-14}	5	10.8	12.7	14.4	17.3	19.8
9.6×10^{-20}	6	12.9	15.3	17.3	20.8	23.7
7.2×10^{-27}	7	15.1	17.8	20.2	24.2	27.7
4.2×10^{-35}	8	17.3	20.4	23.1	27.7	31.7
1.9×10^{-44}	9	19.4	22.9	25.9	31.2	35.6
6.5×10^{-55}	10	21.6	25.5	28.9	34.6	39.6

The molecules of water vapor at 0° C. have an average velocity of 56522^{cm} per sec. The foregoing table shows the

[1] This table was computed by means of the formulæ given by Risteen ("Molecules and the Molecular Theory of Matter," pp. 24–28), which are based on Maxwell's determinations. The high velocities assigned to a part of the molecules are mathematical deductions from data not altogether perfect, and are doubtless to be held with something less of firmness than would be warranted if they were experimental demonstrations, but in the absence of an available method of experimental demonstration these deductions may be accepted as the nearest approximation at present obtainable. A brief non-mathematical statement may be found in Maxwell's "Theory of Heat," pp. 314–316. The results require some modification for mixed gases and for special conditions, but this is not thought essential in this general argument.

number of times this velocity a given proportion of molecules attain at any instant when they have certain specified temperatures. For example, the table shows that when the gas is at 0° C., 47×10^{-1}, or 47 per cent. of the molecules have a velocity greater than the average velocity at zero centegrade; when the gas is at 1000° C., 47 per cent. of the molecules have a velocity 2.2 times the average velocity at 0° C.; when at 1500° C., the same per cent. have 2.5 times the average velocity at 0°C., etc. To raise the velocity of these molecules to the parabolic velocity of the earth the multiplier must be about 19.8 (since 1118127^{cm} per sec. is the parabolic velocity of the earth at the surface and $1118127 \div 56522 = 19.8$, nearly). The table shows that the proportion of molecules attaining this velocity or over (taking the figure nearest to 19.8) is as follows:

For 1000°	1.9×10^{-44}	For 3000°	7.58×10^{-20}
For 1500°	4.18×10^{-35}	For 4000°	9.7×10^{-14}
For 2000°	7.22×10^{-27}		

It now becomes important to ascertain how frequently all the molecules, on the average, will acquire the parabolic velocity of the earth. Every time a collision occurs the velocities of the colliding particles change. The formula for the time required for complete change will therefore be $\frac{1}{NPm}$ where N is the number of collisions per second at 0° C. standard pressure, and Pm is the proportion of molecules having the parabolic velocity, given in terms of 0° C. velocity, standard pressure.

The number of collisions per second for 0° C. standard pressure is given by Maxwell as 17,750,000,000 for hydrogen, 7,646,000,000 for oxygen, and 9,720,000,000 for carbon dioxide. For the number of collisions for water vapor I find no authentic estimate, but it probably sustains the same ratio to the collisions of hydrogen and oxygen that their velocities do to each other, increased by a certain factor representing the effect of the size of the molecules. It will here be assumed that the number of collisions of the molecules of aqueous vapor is 10,000,000,000 per second at 0° C. standard pressure. The results can easily be modified for any other figure that may be thought nearer the

truth. The number of collisions also increases with the density of the gas. In the supposed case of an atmosphere containing all the water of the globe, the density would perhaps be 300 times the standard density. In the upper regions the density would be low and $\frac{1}{100}$ of the standard density may be taken as a representative of the conditions there. Making the assumption that the collisions of water vapor are 10^{10} per sec., the periods required for all the molecules, on an average, to acquire the parabolic velocity of the earth would be as follows:

Temperature	At Standard Pressure	At $\frac{1}{100}$ Standard Pressure	At 300 times Standard Pressure
1000°	1.7×10^{26} years	1.7×10^{28} years	5.7×10^{23} years
1500°	7.6×10^{16} "	7.6×10^{18} "	2.5×10^{14} "
2000°	4.3×10^{8} "	4.3×10^{10} "	1.4×10^{6} "
3000°	33 years	3300 years	40 days
4000°	1030 seconds	28.5 hours	3.4 seconds

Under the current hypothesis of a molten earth derived from a gaseous one the temperature of the atmosphere would probably exceed 4000° C. during the stages of condensation of the refractory material of the earth from the form of a gas to the form of a liquid. From this fervid stage the temperature would fall to 2000° C., or below before the crust would begin to form and the external liquid condition cease. The temperatures of a liquid earth may therefore be assumed to range from 4000° C. to 2000° C. or below, and the figures of the preceding table may be interpreted on this basis.

If the question were simply the acquisition of molecular velocities at the surface of the liquid mass greater than the parabolic velocity of the earth at that point within an available length of time, it would appear that the retention of the water vapor would be put in serious jeopardy during the hotter stages, but that it might survive the cooler ones in large part if it reached them, unless they were very prolonged. But there are other considerations to be taken into account. Under the most favorable conditions only a part of the molecules which attain a speed beyond the limital velocity of the earth's control would

escape because they would not be projected away from the earth. Besides, the escape of molecules projected outwards is seriously limited by the interference of the particles above. This interference is practically prohibitory for the molecules in the base of the atmosphere. The problem, therefore, involves the extent to which the high velocities of the lower hot atmosphere would be communicated to the upper atmosphere whence escape would be possible. The interpretation of this is beset with great difficulties. The molecular velocities of the higher parts of an atmosphere surrounding a molten earth involve factors which cannot be safely estimated from the phenomena of a cold earth. It must of course be assumed that the molecular velocities of the molecules of the rising air would be lowered in proportion to the work done by them or the energy lost, but in convectional movements certain parts of the air are recipients of motion rather than generators of it, and do not lose the energy their movements might seem to imply. It is probable that the interchange of lower and upper air about a molten earth would be extremely violent. It is not unlikely that explosive convection like that of the sun would be the customary mode of action. If hot bodies of vapor were shot violently into the outer limits of the atmosphere, molecular discharge would seem to be probable if not inevitable, whatever might be true of the more quiet mode of action. Besides this the current nebular hypothesis apparently involves the passage of even the outer atmosphere through very hot stages during the early period when the refractory gases of the now solid material were condensing and separating themselves from the atmospheric gases.

The case in this form seems at present indeterminate. There is an apparent probability that a large loss would be suffered while the temperatures ranged from 3000° to 4000°. At the same time there is a possibility that a residue would remain if the period of this high temperature were not prolonged, and a probability that a large part of the atmosphere would be retained if it survived until the temperatures were near the melting point of rock.

The considerations that grow out of altitude above the surface which reduces the parabolic velocity have been neglected thus far. These are not very important in a shallow atmosphere as may be seen by reference to the tables previously given, but they might be consequential in an exceedingly extended atmosphere. While it would be hazardous to estimate the height of a superheated atmosphere embracing the whole present hydrosphere, it seems not improbable that its outer portion would be appreciably affected by the reduction of the parabolic velocity due to its high altitude.

To this is to be added also the effect of the high rotation which the earth is assumed to have had. In the supposed discharge of the moon under either the nebular or fission hypothesis the attraction of the earth in the equatorial zone must have been nearly or quite neutralized by the centrifugal effect of rotation. This must have greatly promoted the expansion of the atmosphere in that zone and correspondingly reduced the earth's power to control its outer portion, indeed it is difficult to see how the moon could have separated from the earth without carrying away the atmosphere, unless indeed the separation took place while the material of both bodies was in a perfect gaseous condition and the atmospheric constituents were diffused throughout the entire gaseous mass. But even in this case the subsequent contraction of the earth should apparently have accelerated its rotation to such an extent that the retention of the outer equatorial atmosphere would be put in jeopardy.

There is still another consideration whose importance may possibly be decisive—the dissociation of water. Dr. Stoney has maintained that even under present conditions the earth is incompetent to retain hydrogen. This conclusion is in harmony with the fact that hydrogen does not permanently exist in the atmosphere, though this absence may be otherwise explained.[1] At 1000° C. all molecules of hydrogen would acquire the parabolic velocity of the earth some hundreds of thousands of times

[1] In his last paper, referred to in a previous footnote, the weakness of the argument from the absence of hydrogen owing to the ease with which it may combine

per second. Now the temperatures of the supposed molten earth reached and probably much exceeded the temperatures of effective dissociation of water vapor. The dissociation is probably due to violent impact of molecules of high velocities. It probably takes place in some degree even at moderate temperatures.[1] The proportion of dissociated molecules greatly increases with temperature until the dissociation so far exceeds the recombination that it may be said to be nearly or quite complete. Authorities differ as to the temperature of effective dissociation. The estimates commonly given lie in the lower half of the range of temperatures above assigned to the molten stage of the earth. If, therefore, the temperatures of the molten globe ranged as high as the current hypothesis seems to require, the dissociation of the aqueous vapor would seem to be inevitable and the loss of hydrogen would be endangered notwithstanding its disposition to recombine.

If the retention of the atmosphere be put in jeopardy by the earth's temperatures in a supposed liquid state much more would it be endangered if the temperatures were those of volatilization of the refractory material of the earth, as assumed by the Laplacean hypothesis, for not only would the molecular velocities be enormously increased, but the extension of the mass would push its exterior portions out into the regions of low parabolic velocity.

If the mass be still further dispersed into the vast gaseous ring of the Laplacean hypothesis the argument from molecular velocities is immeasurably strengthened, for not only must the temperatures requisite to the retention of the refractory substances of the earth in the attenuated condition of such a gaseous ring be exceedingly high, but the parabolic velocity of the body

with the free oxygen of the air is in a large measure covered by resting the argument chiefly on the absence of helium, which is chemically very inert. As helium is given off slowly by hot springs, it is urged that in the vast lapse of the geological ages it should have accumulated to an appreciable quantity if it had not escaped. As it has twice the molecular mass of hydrogen it is held that the "minimum speed of control" at existing temperatures lies below the molecular velocities of gases which are twice as heavy atomically as hydrogen.

[1] RISTEEN, Molecules and Molecular Theory, pp. 50–51.

in such an extremely distributive form would be exceedingly low. It would seem, therefore, that unless the argument from molecular velocities is radically and grievously at fault the hypothesis of a gaseous earth-moon ring is untenable unless a degree of tenuity be assumed which separates the molecules beyond the limits of effective kinetic relations. In this case the argument from rapid cooling becomes peculiarly strong and seems to leave no alternative but the conversion of the refractory matter of the ring into the discrete solid condition.

Impressed by these considerations and following what seem to be the legitimate implications of molecular studies, I have ventured for myself to place the atmospheric inferences from the supposed gaseous and molten conditions of the primitive earth in the list of uncertain deductions and to add an alternative hypothesis to my working list.

But occasion for doubt concerning an early molten earth and its vast atmosphere is not limited to this line of approach. On other grounds we cannot fail to recognize that some form of the meteoroidal hypotheses of the origin of the earth is entitled to be reckoned among the possibilities. Whether an accretion of meteoroidal matter would give rise to a molten earth or not would depend upon the rapidity and violence of the infall. If the intervals between falls were sufficient the heat would be lost concurrently. A relatively cold earth is theoretically as possible as a hot one until it is shown that the aggregation must be rapid. Even following the general line of the nebular hypothesis a cold earth is hypothetically possible. We have found reason for thinking that the earth-moon ring, if formed, would probably become cooled to discrete solid particles while still in the ring form. Now it does not appear that there are any conditions inherent in such a ring that tend toward sudden concentration into a spheroidal body. Quite on the other hand, the problem presented by such a ring is to find agencies which will lead to its concentration at all. Just how the concentration would take place is an unsolved question.[1] But two things seem certain; first,

[1] I have ventured to speculate a little upon this, though beyond the province of a

the process would be slow; the individual conjunctions more or less distant in time, and the heat generated by one impact so far forth lost before another took place; second, the conjunctions would not be opposing collisions but overtakes in which both bodies were moving at nearly the same speed, and the heat of conjunction hence relatively small. It would appear, therefore, that the aggregation might take place without the development *at any one time* of a general high temperature. The present accretions of the earth show us that growth is possible without notable increase of temperature. Following the general line of the nebular hypothesis, therefore, it is possible to suppose the earth to have been affected by relatively low surface temperatures at all stages of its growth. By changing our assumptions as to the rate and vigor of accretion we can correspondingly change our conclusions respecting the earth's temperature. The range

geologist, because it involves a supposed objection to meteoroidal aggregation. In a solid rotating ring the outer part moves faster than the inner and if broken and condensed to the globular form the rotation must be direct. But in a ring of planetoids the inner members move faster than the outer and if the several concentric orbits be symmetrically drawn together so that the inner planetoids uniformly or usually collide with the inner sides of the outer planetoids *retrograde* rotation follows. But this is inconsistent with the facts of the solar system except in the case of Uranus and Neptune (Cf. Faye, sur l'Origine du Monde, 1896, pp. 165, 270–281). But it seems improbable that this would be the mode of union except in the case of the outer planets, for the mutual gravitation of minute planetoids is very slight and expresses itself chiefly in perturbations under such conditions (see On the Stability of Motion of Saturn's Rings, Scientific Papers of James Clerk Maxwell, Vol. I, pp. 288–376), while the disturbing influence of the great planets is appreciable, as the ellipticity of the orbits of the planets testify. If the orbits of the particles or planetoids of the supposed earth-moon ring were at first nearly circular and concentric the conjoined attractions of the outer planets would render them elliptical. But the line of their apsides would not be concordant and would be subject to subsequent shifting in a more or less non-concordant fashion. It is therefore conceived that they would be brought to cross each other and that this would lead to collisions. Now an outer orbit could only cross an inner one by a more or less perihelion portion of it coming into coincidence with a more or less aphelion portion of the inner one. But the perihelion movement of a body in an outer orbit is greater than the coincident aphelion movement of a body in an inner orbit. Hence on the average the outer body in collision will have the greater speed and the consequent rotation will be direct. As this reasoning applies to the inner planets and not to the outer, and as the inner planets have direct rotations while the outer probably have retrograde rotations, it has at least the merit of coincidence with the facts.

of rational hypothesis seems therefore to be wide. It is herein urged that it is wholesome at present to recognize this wide range in its fullest amplitude.

But if we question current conceptions we should present alternatives which account for the atmosphere and for internal heat. Let us therefore hastily follow the hypothetical growth of a planet built up by the slow aggregation of small bodies which join it at low velocities and develop a minimum heat. Let the case be purposely made rather extreme to develop sharply the difficulties springing from it. Let the infalling particles be small and their rate such as not to generate a high surface temperature. The growth of such a body up to the size of the moon may be taken as an hypothesis of lunar history and the phenomena of the moon may serve as a check upon it. The moon may, however, have originated by fission even though the earth were built up by accretions. In the early stages of growth the gravity being low the aggregation may be supposed to have remained uncondensed. Volcanic aggregations of bombs, cinders and ashes are perhaps the nearest terrestrial analogues. The ingathering particles obviously carried with them so much of the atmospheric material as was entrapped or occluded within them in their solidification, or was absorbed into their pores or adhered to their surfaces. Judging from meteorites the amount of this might have been large. Gaseous molecules moving as independent bodies may have joined the aggregation and become absorbed in its porous body, but they would not have been collected into an appreciable atmospheric envelope until the body passed the size of the moon if the molecular considerations urged earlier in this paper hold good, though an atmospheric envelope would not have been entirely absent. As the mass grew the central pressure increased and condensation produced heat at the center proportional to the work done. I find the explanation of internal heat chiefly in this self-condensation, it being essentially the application of the Helmholtz solar theory to a solid body. Tidal kneading and chemical action doubtless added their contributions. When the growing mass reached the

size of the moon a definite problem was presented of which the present moon stands as a possible representative and invites computation. If in its loose state of aggregation the mass had a specific gravity of 2. and if it shrank by self-condensation to 3.4, the average specific gravity of the moon, the possible heat generated by the gravitative fall would have equaled 3900° C. for the whole mass, the specific heat being assumed to be .2, which is very prudent. I owe the computation to Mr. Moulton. For convenience of computation the condensation was assumed to be uniform and the distribution of heat uniform. The original distribution of internal heat would perhaps have varied with the square root of the pressure, according to Laplace's formula. As the computed temperature is more than twice the melting temperature of average rock not under pressure it seems ample for all igneous phenomena indicated on the moon with a large residue for secular loss.

Assuming that the exterior temperature remained below zero during the pre-atmospheric stages of growth, the hypothetical structure of the planet when it reached the size of the moon may be pictured as embracing (1) a dense central portion raised to a high temperature by compression, giving a potentiality of liquefaction under relief of pressure; (2) a zone of declining temperature and less compressed structure, graduating toward a porous condition, and (3) at the surface the still unconsolidated open aggregation. The low average specific gravity of the moon (3.4) encourages the belief that the outer porous zone was deep and open. The notion is entertained that the central heat and compression would lead to the expulsion of a part of the centrally entrapped gases and vapors, and that these would be driven outward into the exterior porous portion, which having a low temperature, like that of the moon today, condensed the aqueous vapor in the spaces of the open texture and the whole became bound together more or less completely with a matrix of frost and ice. It is assumed that the internal condensation would be attended by readjustments of matter of the nature of diffusions, differentiations and concentrations, and that there

would be deformations and igneous extrusions as on the earth today. Perhaps the reduction of metallic oxides and the working of the slag toward the surface may have been an incident of the process. Now whenever igneous extrusions invaded the zone of congealed vapor conditions would be afforded favorable for the generation of great quantities of steam temporarily restrained by the overlying fragmental mass and facily subject to explosive discharge. The peculiar constitution of such a body invites the notion of exceptionally explosive eruptions, as do also the extraordinary pits of the moon. As a matter of fact the suggestion arose from studying the pits and not from the peculiar constitution of the body to which the speculation had led. These remarkable cavities seem to be the close analogues of the few explosive craters which the surface of the earth presents.

The pre-atmospheric stage of the evolution would obviously cease when the growing earth acquired a size sufficient to measurably control its exhaled and ingathered gases. A certain measure of control was incidental to all stages, for even a small planetoid has some power to control gases of very low initial velocity if it continues at low temperatures. At the size of the moon gases of much more than the average molecular velocity of those of the earth at 0° C. could be held if their velocities were not exalted by interaction. This exaltation would become ineffective when the gases became extremely rare and the surface very cold. The molecular argument does not therefore affirm the total absence of an atmosphere on the moon, but rather on the contrary its scanty presence. An effective control would perhaps begin to be gained by the growing planet when the size of Mercury or thereabout was attained. After this the vapors and gases of lower molecular velocity would collect upon the surface and initiate the appreciable history of the external atmosphere. Whensoever the accretions of this atmosphere acquired the power of retaining the heat of the sun to such a degree as to give a surface temperature above the freezing point, the inauguration of the hydrosphere would take place and with its pro-

gressive development the familiar phenomena due to superficial waters would appear. The surface would soon lose its extremely fragmentary condition and take on the terrestrial form; the subterranean frozen zone would disappear and the vulcanism assume the terrestrial type.

This hypothesis, it will be observed, departs radically from the familiar view in that it initiates the atmospheric history by a tenuous envelope which continued to slowly increase. By the hypothesis, as thus far sketched, the atmosphere was derived from the interior. After the earth reached the requisite size the collection of wandering gases would supplement it. The competency of this external source is almost wholly a matter of conjecture and its vague possibilities need not be discussed here. It need only be remarked that the hypothesis of molecular discharge involves the peopling of space with flying molecules.

The measure of competency of the interior to supply an atmosphere is obviously a critical question. Unfortunately we are almost entirely without specific quantitative data bearing on the subject. We know that there is not a little atmospheric material in the interior as demonstrated in volcanic action and in the content of the minute pores of the hypogene rocks, but we do not know how far this was derived from the surface. If the moon never has had an appreciable external atmosphere its explosive eruptions were not due to surface infiltration and the implications of its numerous and vast craters are very suggestive. We can also draw inferences from meteorites which sometimes contain several times their volume of gases, as well as solid matter susceptible of conversion into atmospheric constituents. But at best we can only form very vague quantitative notions. On the other hand, we are liable to overestimate the amount required. The atmosphere and the ocean combined are little more than $\frac{1}{5000}$ of the mass of the earth. To be competent, the ingathered matter need therefore only contain about $\frac{1}{50}$ of 1 per cent. of atmospheric and aqueous material, plus an added factor for what may have been lost and what still remains in the interior. This percentage does not seem large enough

to render the hypothesis improbable in the present state of knowledge.

The competency of self compression to generate the internal heat of the earth is also a critical question already touched upon. Estimates made by different methods seem to give an ample supply. The safest seemingly is that of Mr. Moulton who simply computed the energy that would be required to lift the matter of a homogeneous earth of 5.6 sp. gr. against gravity alone to such a height as to give the whole a uniform specific gravity of 3.5. This is more than the present specific gravity of the moon and is obviously extremely conservative. The fall of this matter was found capable of raising the whole mass (specific heat being taken at the over-figure of .2), to 6560° C., or about four times the average melting point of rock at the surface. If the original specific gravity be taken at 2. on a gross average, which seems much more probable than 3.5, when the supposed loose state of aggregation is taken into account, the possible temperature, if all the potential energy were converted into heat and retained, would exceed 13,000°. A portion of the energy might take other forms than heat and a portion would be lost concurrently, but as the heat was generated in the interior and must have been conducted to the surface very slowly, the secular loss must have been of the conservative order. On the other hand, tidal friction and possibly chemical action would add to the interior heat and more or less offset these sources of loss. On the whole, therefore, self condensation seems a competent source of internal heat unless the rate of aggregation was excessively slow.

Although aside from my central purpose, it may be remarked that the recognition of a progressive self-condensation of the earth from a loose aggregation to a more dense one by a prolonged and still incomplete process presumes a degree and quality of shrinkage peculiarly suited to explain the inequalities of the earth's surface. An explanation must be found not only for the mountainous wrinklings of the crust in post-Cambrian times and the great crumplings and crushings of the Archæan

ages, so much neglected, but also for the great continental elevations and their superposed plateaus, and the deep oceanic depressions with their abyssmal anti-plateaus—phenomena with which current hypotheses have struggled so unsatisfactorily. It is also necessary to find an explanation for the unequal distribution of densities which have been partially revealed by gravity observations, but which are more broadly suggested by the unsymmetrical aggregation of the hydrosphere. The total shrinkage of the earth from first to last, under the hypothesis here proposed, would perhaps be sufficient to reduce its volume as much as one-half or even more, this, of course, depending on the original density. While the most of this contraction would antedate known geological history, the process can scarcely be supposed to have been complete in pre-Cambrian times, or even to be complete now. A part of the condensation must, therefore, quite certainly have fallen within geological history, and a part must remain yet to be accomplished, for, in addition to the retardation of the process of condensation caused by the heat generated, by the rigidity of the outer rocks and by the rapid rotation of the sphere, the maximum condensation of the mass could only be attained by means of a general rearrangement of the heterogeneous material of the meteor-built globe through the agency of diffusion, segregation, re-combination, re-crystallization and other processes which aid in giving a maximum compactness to mixed material. This internal readjustment must necessarily have been a slow process if the globe has been solid throughout its entire history, and must doubtless be yet incomplete. This progressive rearrangement of internal material adds a special agency of contraction to loss of heat, change of rotation and similar processes now recognized and which would act under this hypothesis essentially as under the current view.

If we make the plausible assumption that a slow process of diffusion, differentiation, concentration and gravitative readjustment has been in progress throughout the whole history and is yet active, and that matter has crept up from the hot compressed center into the superficial parts where relief of pressure would

cause liquidity, we seem to have an equally facile basis for the explanation of molten extravasations.

It may also be remarked that the acquisition of an atmosphere and hydrosphere at a moderate temperature when the growing earth reached a medial size introduced conditions congenial to life at a stage sufficiently anterior to the Cambrian period to satisfy the most strenuous demands of theoretical biology. Most of the restrictive arguments of Lord Kelvin and others lose their application under this hypothesis.

Returning to the atmospheric problem, it is to be remarked that the assumption of a limited early atmosphere may be entertained quite apart from the foregoing accretion hypothesis. Under the current hypotheses of the separation of the moon, whether by the annular mode of Laplace or the fission mode of George Darwin, great rotary speed and high temperature are assumed as necessary or probable conditions. We have seen that these seem to put the retention of the atmosphere in jeopardy. The balance of theoretical probabilities, as I now see them, favors the presumption that the atmosphere would have been greatly reduced under these conditions. There does not therefore seem to me any firm ground, even on current theories of the earth's origin, for insisting on the acceptance of the doctrine of a vast primitive atmosphere, as the great reservoir from which subsequent abstractions have been chiefly taken. I think we are free, therefore, to assume just such a Palæozoic atmosphere as the life and deposits of that time seem to imply, interpreted by the phenomena of today. Such an interpretation seems to me to indicate conditions not radically dissimilar to those of the recent geological ages; warm climates in high latitudes at times, colder climates in lower latitudes at times, moisture at times, aridity at times, and like oscillations. This view carries with it the necessary corollary that the atmosphere has been supplied by accessions in some near proportion to its losses. That additions have been made to the atmosphere of vital importance is a familiar doctrine, but it is here pressed to an unfamiliar degree.

If we push the doctrine thus far it is important to assign causes for the fluctuations of supply and exhaustion of the atmosphere, to give the doctrine a working form and to devise means of putting it to the test. Concerning external sources of enrichment we know so little that we can scarcely say that there is a leaning of probabilities either toward or against practical uniformity. The internal supplies were probably correlated in some measure with igneous extravasations—not that such extravasations were the sole mode of liberating gases, but that other modes probably worked concurrently with them. The escape of gases was probably also correlated with crustal movements, especially those that compromised the continuity of the surface rocks, particularly the profound crushings which mining and the microscopic study of the hypogene rocks reveal. In these phenomena therefore, may be found a rational basis for inferring the times of probable atmospheric enrichment. Formulated as a proposition, it may be postulated that special enrichment coincided with special igneous extravasation and crustal disruption, taking the earth as a whole. The supply may be assumed to have been uniform in so far as these and other means of liberation were on the average uniform.

The phases of depletion are susceptible of more satisfactory treatment. In the first place, the depletion was differential. The loss of nitrogen was doubtless slight, because of its chemical inertness, and hence, though the supply may have been small, the nitrogen grew to ultimate dominance. The depletion of oxygen through the alteration of surface rocks was notable, but less than that of carbon dioxide. As a result the latter became *the minimum factor of the atmosphere and the critical one.* The enormous reserve supplies of water rendered its consumption inconsequential.

In the second place, the depletion was conditioned upon the exposure of the surface rocks to atmospheric alteration. This in turn was conditioned upon topography. In stages of elevation the water table of the land is depressed and the zone of atmospheric penetration is deepened. At the same time the

zone of effective penetration of aerated water below this is also deepened. Hence the alteration of the rocks is promoted. In stages of low elevation — stages of baseleveling, for example — the zone of atmospheric penetration is shallow and rock alteration proceeds slowly. From this may be deduced the law that during stages of depression or baseleveling, depletion proceeded slowly. The aggregate surface must, of course, be considered.

To apply this law, let us assume for the moment, a uniform supply equal to the *average* rate of exhaustion. With the inauguration of any great epoch of general uplift there would begin an era of relatively rapid atmospheric exhaustion, which would proceed continuously during such elevated stage and might result in notable atmospheric impoverishment, as the computations cited early in this paper show. As the cutting down of the surface approached baselevel, the depletion would be retarded and, the supply continuing the same by hypothesis, the rate of exhaustion would fall below that of supply and an epoch of enrichment begin. A second elevation would re-inaugurate the depletion, and so oscillations of enrichment and impoverishment would follow the general oscillations of the land surface.[1] Applying this law by itself, atmospheric poverty should follow *at some distance* the stages of general elevation, and, on the other hand, atmospheric enrichment should follow at some distance the stages of baseleveling or depression.

But the assumption of a uniform average supply needs revision. In the main the igneous extrusions and crustal disruptions that are presumed to favor gaseous emanation probably fell in with the initiation of the elevated stages that favored depletion. In a general way the curves of supply and of depletion ran together in geological history and gave a measurably

[1] More strictly, the oscillations of that part of the land surface whose rocks consumed the atmosphere by their alteration — in general terms, the crystalline areas. Periodic general elevations followed by general baselevelings or some notable approach to baselevelings, are here assumed. It would be obligatory to state the grounds for this in an ampler discussion, but the all too narrow limits of this paper make this impracticable.

constant atmosphere, but their occasional failures to run in consonance are herein assigned as possible causes of exceptional climatic episodes, for it is almost axiomatic to say that climatic changes would attend changes in the constitution of the atmosphere. I assume that atmospheric poverty, especially in the critical item of carbon dioxide, is correlated with low temperature, as urged by Tyndall and others.

It is impossible here to attempt to apply the doctrine in detail to geological history. But it may be noted in passing that the Pleistocene glaciation followed at a notable interval the formation of the great plateaus and epeirogenic uplifts of late Tertiary times. The glaciation of India, Australia and South Africa occurred about the the time of the crustal revolutions that marked the close of the Palæozoic era. The uncertainty of the homotaxis of the strata involved makes a precise correlation at present impossible. The glaciation perhaps came too early to fit the hypothesis.[1] Here, at least, is an excellent chance to put it to trial. All other hypotheses of glaciation have fared badly when brought to the supremely severe test of the ancient oriental low-latitude glaciation, and if this hypothesis shall follow them to the junk shop of broken down theories it will find an already beaten path. The glaciation of northern Norway as determined by Reusch and Strahan succeeds the pre-Cambrian stage of elevation, but in what precise relations is not known.

The great extensions of warm climate to the high north appear to be associated with baseleveling periods in a general way ; but whether in a specific connection of sufficiently declared nature to indicate the relation of cause and effect remains to be determined.

Another source of atmospheric depletion needs recognition. Dr. S. W. Johnston is responsible for the opinion that the entire carbon dioxide of the atmosphere would be removed by the present annual growth of vegetation if there were no return through decomposition and animal life provided it were continued uni-

[1] It may fall under the organic factor of the hypothesis mentioned later.

formly for one hundred years.[1] Animal life, however, makes such nearly complete returns that the permanent loss is usually regarded as negligible. Nevertheless it is something. In certain stages of the world's history it has been important, as the coal beds testify. The loss in the Carboniferous age has been held sufficient to remove a noxious excess from the early atmosphere. On the same basis it might be held to cause serious depletion in the absence of the excess. It is necessary at least to consider whether, under the theory of a limited early atmosphere, conditions which restrain the animal factor of the organic cycle may not so far impoverish the air as to seriously affect climate. But this cannot be entered upon here. The organic cycle is very sensitive and very rapid in its action. It would naturally be greatly influenced by the topographic conditions which were concerned in the supply and exhaustion of the atmosphere, and lend to them either its concurrent or its counteracting influences.

It is now a little more than fifty years since Tyndall suggested that the periods of terrestrial glaciation might be dependent upon the carbon dioxide of the atmosphere whose peculiar competence to retain solar heat he had demonstrated. The suggestion of the origin of glaciation through the depletion of this atmospheric constituent is, therefore, not at all new. It has been entertained by others than Tyndall. If it has failed to find much acceptance this has perhaps been partly from a doubt as to its adequacy and partly from the lack of any definitely assignable cause for the requisite intermittent depletion. Dr. Arrhenius has recently contributed to the subject a most important discussion bearing especially upon the former point.[2] By an elaborate mathematical analysis of data derived from Langley's experiments he has endeavored to ascertain what degree of depletion of the carbon dioxide of the present atmosphere would bring on the conditions of Pleistocene glaciation, and, on the other hand, what degree of enrich-

[1] How Crops Feed, p. 47.

[2] Svente Arrhenius, Phil. Mag. S. 5, Vol. XLI, No. 251, April, 1896, pp. 237–279.

ment would produce the warm climate of the Tertiary. He arrives at the conclusion that the removal of 38 to 45 per cent. of the present carbon dioxide would bring on glaciation and that an increase of 2.5 or 3 times its value would produce the mild temperatures of the Tertiary times. He quotes the opinion of Professor Högbom in support of the competency of earth changes to produce this depletion, and also the competency of the interior and other sources to re-supply the impoverished atmosphere. He, therefore, carries the suggestion of Tyndall and others a very notable step in advance, and, what is especially important, has given it quantitative expression on the basis of deductions from observed data. He does not, however, postulate the conditions which control the enrichment and depletion of the atmosphere which has been the essential endeavor of this paper.[1]

But we do not meet geological demands when we simply offer *general* explanations of climatic changes. Our theories must ultimately be found to fit the precise phenomena. How are we to explain the profound glacial oscillations? Here is where existing hypotheses are put to the stress and our atmospheric hypothesis seems at first thought even less adaptable to the phenomena than most others. If we could deny that the oscillations were profound, as some do, it would be convenient. But I fear we cannot. We may appeal to variations of atmospheric supply, to the precession of the equinoxes, etc., but field experience leads me to doubt whether these will fully fit the phenomena, though they must doubtless be reckoned as factors. I have endeavored to follow out the doctrine of atmospheric gain and loss on its own lines, and although the studies are incomplete, the results are at least encouraging. I seem to find a rhythmical action that may in part explain the glacial oscillations. To do it justice it should have elaborate and careful statement, but I can here only suggest its nature in bald outline

[1] I may here remark that the main features of the ideas herein advanced were entertained and expressed to my students some time before I saw Dr. Arrhenius' important paper, but I fear I might not have felt justified in giving them a more public statement but for the encouragement of his weighty opinion on the vital point of quantitative sufficiency.

and in terms that need qualification. The idea hinges (1) on the action of the ocean as a reservoir of carbon dioxide and (2) on the losses of the organic cycle under the influence of cold. Cold water absorbs more carbon dioxide than warm water. As the atmosphere becomes impoverished and the temperature declines, the capacity of the ocean to take up carbon dioxide in solution increases. Instead, therefore, of resupplying the atmosphere in the stress of its impoverishment, the ocean withholds its carbon dioxide to a certain extent, and possibly even turns robber itself by greater absorption, though the diminution of the tension of the carbon dioxide of the atmosphere as its amount is reduced tends to increase the discharge of carbon dioxide from the ocean to restore the equilibrium, and, to the degree of its efficiency which is undetermined, offsets the increased absorption of the cold water. So also, with increased cold the process of organic decay becomes less active, a greater part of the vegetal and animal matter remains undecomposed, and its carbon is thereby locked up, and hence the loss of carbon dioxide through the organic cycle is increased. The impoverishment of the atmosphere is thus hastened and the epoch of cold is precipitated.

With the spread of glaciation the main crystalline areas, whose alteration is the chief source of depletion, become covered and frozen, and the abstraction of carbon dioxide by rock alteration is checked. The supply continuing the same, by hypothesis, reënrichment begins, and when it has sufficiently advanced warmth returns. With returning warmth, the ocean gives up its carbon dioxide more freely, the accumulated organic products decay and add their contribution of carbonic acid, and the reënrichment is accelerated and interglacial mildness hastened.

With the reëxposure of the crystalline areas, alteration of the rocks is renewed and depletion reëstablished and a new cycle inaugurated. And so the process is presumed to continue until a change in the general topographic conditions determines a cessation.

The rhythmic curve which represents these oscillations should have an increasing or declining amplitude, according to the advance or decline of the topographic conditions which control the depletion of the atmosphere. This brief sketch needs much elaboration and qualification, but as the studies are still in progress, and the paper has already transgressed the limits due the occasion, it must be deferred.

T. C. Chamberlin.

AN ANALCITE-BASALT FROM COLORADO.[1]

THE discovery that analcite plays the rôle of an important primary constituent of certain igneous rocks must be regarded as one of the most interesting developments of recent petrographical investigations; and I, for one, am inclined to believe that Pirsson has not gone too far in his general conclusions, published in this JOURNAL a year ago,[2] that analcite is an essential, primary component of many rocks now assigned to the monchiquites, a rock group described some years ago by Hunter and Rosenbusch. As each definitely proven instance of primary analcite in igneous rocks must for some time to come be of value in establishing its true rank as a rock constituent, the following description is offered, although some important details of occurrence cannot be given.

The rock in question was found by myself in 1893, while engaged in the geological survey of the Pike's Peak quadrangle. The exact locality, which may be identified by reference to the published map of that area,[3] is in the small park called "The Basin," twelve miles nearly west of Cripple Creek. Near the southern end of The Basin, and on its western side, at the end of a little ridge between two branches of High Creek, there is an outcrop of black basaltic rock directly on the line where a great complex of andesitic and basaltic breccia and agglomerate rests on the Dakota Cretaceous sandstone. This volcanic series extends far to the westward, between South Park and the Arkansas River, but only a few tongues and remnants now exist to the eastward of The Basin. The outcrop mentioned was regarded

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] "The Monchiquites or Analcite Group of Igneous Rocks," by L. V. PIRSSON. JOUR. GEOL., Vol. IV, 1896, pp. 679–690.

[3] Geological Atlas of the United States, Pike's Peak Folio (No. 7), Washington, 1894.

at the time of discovery as indicating a short dike parallel to the ridge, but no contact was seen, owing to detritus. Although the rock had a somewhat unusual habit, it was not supposed to be materially different from many other basaltic dikes which had been observed cutting the fragmental series referred to. It turns out on examination, however, that this rock of The Basin is an analcite-basalt, quite unlike any other rock collected in the entire district.

The rock is dark and very fresh looking, with many small crystals of augite and olivine, and a white mineral occurring in roundish grains, all these averaging about 1^{mm} in size. A few augite prisms are larger, and terminations exhibiting the usual pinacoidal twinning were seen. The white mineral, by its rounded grains and the absence of cleavage, presents the only marked deviation from the normal habit of the neighboring plagioclase-basalts. A black, aphanitic groundmass holds the phenocrysts.

Under the microscope augite, olivine, and magnetite possess a development common in basalts. Augite of pale, yellowish green color, and very faint pleochroism, occurs in phenocrysts, which are usually almost free from inclusions, but a few aggregates of similarly colored grains are full of irregular or sack-shaped glass inclusions. There is commonly a narrow outer zone to the purer augite, in which inclusions of glass and magnetite are seen, and the substance of this outer rim has a faint purplish tinge, like that of the smaller groundmass grains. An analysis of the pure augite is given below.

Olivine appears in moderate abundance, of usual habit, and is the only mineral showing any sign of alteration. Perhaps half of the olivine is serpentinized with pale brown biotite leaves inclosed in the serpentine of the most altered grains, as an apparent secondary product. Primary dark, reddish brown biotite also appears very sparingly. Magnetite and apatite have the customary development.

A considerable part of the rock is colorless and isotropic in polarized light; a much smaller part is colorless but doubly refracting, and is mainly assignable to three species of feldspar.

The isotropic constituent embraces most of what is megascopically visible, and also much more, in small grains, which, with corresponding ones of augite, magnetite, and feldspar, make up the groundmass. There is, in fact, a regular gradation between large and small isotropic grains. No crystal form was observed for the isotropic substance, but neither does it appear in any way to play the rôle of a glassy base. It seems throughout to be an irregularly granular mineral constituent, of the isometric system.

The larger grains are almost wholly free from inclusions, and while probably the last substance to crystallize the isotropic mineral has in its growth pushed back the smaller grains of augite and magnetite so that they often form a distinct zone about it. This phenomenon seems clear evidence of a crystallizing force. The smaller grains mingle with augite, magnetite, and feldspar.

While no crystal form has been observed, rings or wreaths of small inclusions were noticed in a few grains, and these so strongly suggested leucite that until the chemical analysis was made I felt quite sure that the rock must be a leucite-basalt. A smoky tinge is present in a very few grains, and in one the coloring matter is arranged in zones, clearly suggesting a regular crystal form. Irregular fractures traverse the substance, and its index of refraction is less than that of the Canada balsam, as indicated by Becke's method.

The feldspathic constituent appears in small, irregular, clear particles, some of which have most characteristic microcline structure, with an extinction of 15°; others can only be considered as sanidine, with Carlsbad twinning in some grains; and the remainder is a plagioclase rich in soda, with very delicate albitic twinning. Its angle of extinction is always small. There is possibly some nepheline associated with the feldspar.

The purity, freshness and abundance of the isotropic mineral invited the attempt to determine its composition by isolation and analysis. This was done by Dr. W. F. Hillebrand, and the result is given in column I of the table below. Under I^a is given the molecular ratio deduced from the analysis. The

amount and composition of the portion of the rock soluble in hydrochloric acid is shown in column II. The augite was, in the main, so free from inclusions that an analysis was made by Dr. Hillebrand for comparison with other rock augites. The material was isolated by the Thoulet solution, and was found to be very pure on microscopical examination. III is the analysis of the augite.

	I	Ia	II	III
SiO_2	51.24	854	21.97	49.26
TiO_2				1.53
Al_2O_3	24.00	235	9.94[3]	6.01
Fe_2O_3	1.20[4]		3.71[4]	3.31
FeO				4.23
CaO	1.62	29	1.95	21.79
SrO	.06		.08	.06
BaO			?	?
MgO	.33	8	2.87	12.40
K_2O	1.25	13	.56	.41
Na_2O	11.61	187	4.04	.79
H_2O	.62[1]		3.91[5]	
H_2O	8.47[2]	470		
P_2O_5				
SO_3	none			
Cl	trace		.05	
	100.40		49.08	99.79

[1] Over H_2SO_4.
[2] Remainder of water.
[3] Includes P_2O_5.
[4] Total iron as Fe_2O_3.
[5] Assumed from rock analysis.

The isotropic mineral could not be secured entirely free from attached or included particles of doubly refracting substances. But these made up a small part of the material subjected to analysis. After treatment with hydrochloric acid there remained an insoluble residue, amounting to 4.22 per cent. of the substance taken, and this was found on microscopical examination to consist of augite and feldspar. From the molecular ratio the following proportion may be derived:

$$SiO_2 : Al_2O_3 : R_2O : H_2O :: 854 : 235 : 237 : 470 \text{ or } 3.6 : 1 : 1 : 2.$$

In this result CaO and MgO are united with the alkalis and iron

is neglected. This ratio is exactly that of analcite except for the silica. It cannot be assumed that the material isolated was pure, and small amounts of various substances no doubt went into solution. But we can reasonably consider it demonstrated that the isotropic substance acting like a mineral constituent has practically the composition of analcite. I can see no reason for doubting this identification.

The analysis of the soluble portion of the rock leads to practically the same result as that of the isolated analcite. By deducting olivine, apatite, and magnetite, there remains a residue having about the ratio 1 : 1 for Al_2O_3 to alkalis. Silica is again low. If nepheline were present in the rock the low silica of both analyses might be explained. It is possibly there in some small amount but probably not in sufficient quantity to entirely explain the figures of the analyses.

The augite proves to be quite high in alumina and to have more titanic acid than would be inferred from the pale violet tinge it exhibits. It is thoroughly normal augite.

An analysis of the rock of The Basin was also made by Dr. Hillebrand, and it is given in column IV of the following table, in which analyses of several allied rocks are introduced for purposes of comparison. Of the other analyses, V is of a rock from Shelburne Point, Vermont, described by J. F. Kemp and V. F. Marsters,[1] with other dikes of the Lake Champlain region. In the original description Kemp published another analysis of this rock, the accuracy of which he was afterward led to question, and the analysis here quoted, made by H. T. Vulté, was published by Pirsson, at Kemp's request, in his cited discussion of the monchiquite group. VI is of one of the original monchiquites from Brazil, by M. Hunter.[2] The relation between the analcite-basalt and the other basalts of the region is illustrated by analysis VII, by W. F. Hillebrand, of a normal plagioclase-basalt occurring in Saddle Mountain, a few miles northwest of The Basin.

[1] The trap dikes of the Lake Champlain region. Bull. 107, U. S. G. S., 1893 p. 32

[2] Über Monchiquit, ein camptonitisches Ganggestein aus der Gefolgschaft der Elæolithsyenite, Tschermak's Min. und petr. Mitth. Vol. XI, 1890, p. 445.

TABLE OF ROCK ANALYSES.

	IV.	V.	VI.	VII.
	Analcite-basalt, The Basin, Colo. W. F. Hillebrand.	Monchiquite, Shelburne Point, Vt. H. T. Vulté.	Monchiquite, Brazil. M. Hunter.	Plagioclase-basalt, Saddle Mt., Colo. W. F. Hillebrand.
SiO_2	45.59	45.58	46.48	48.76
TiO_2	1.32	undet.	.99	1.65
ZrO_2	.03	....	....	none
Al_2O_3	12.98	15.87	16.16	15.89
Fe_2O_3	4.97	4.65	6.17	6.04
FeO	4.70	6.37	6.09	4.56
MnO	.14	trace	....	.13
CaO	11.09	9.91	7.35	8.15
SrO	.12	....	....	.06
BaO	.13	....	....	.17
MgO	8.36	8.32	4.02	5.98
K_2O	1.04	1.61	3.08	2.93
Na_2O	4.53	3.42	5.85	3.43
Li_2O	trace	....	....	none
H_2O	.51	3.14	4.27	.40
H_2O	3.40			1.48
P_2O_5	.91	....	....	.60
Cl	.05	....	....	....
CO_2	....	....	.45	....
S	....	....	....	....
	99.87	98.87	100.91	100.23

Were the greater part of the water in the analcite-basalt deducted, and the remainder recalculated to 100, the analysis IV might stand for an ordinary nepheline-tephrite. It is lower in alumina than many analyses of basalt, but if TiO_2, P_2O_5, and MgO were accurately estimated in all such rocks the alumina would often fall 2 or 3 per cent. below the published figures. The magma of this basalt was relatively quite rich in soda with low silica and much water. The formation of analcite in the final stages of consolidation of such a magma seems to me much more natural than that glass should be the result, provided only that the conditions were in general favorable to crystallization. As the rock probably occurs in a dike and in a region where there are many dikes of holocrystalline plagioclase-basalt, the presumption must be that the conditions were favorable to crystallization.

The monchiquite of Shelburne Point agrees very closely in composition with this analcite-basalt. Its high alumina would no doubt be materially reduced if TiO_2 and P_2O_5 were deducted. Of this particular rock Kemp quotes Professor Rosenbusch, to whom it had been shown, as saying that it is a "true monchiquite of typical habit."[1] From a microscopical examination of a specimen of this rock which is in the reference collection of the Geological Survey it is plain that there is a great difference in the development of the two rocks. In the Shelburne Point rock there is a cloudy gray base of indistinct radially fibrous structure and of weak double refraction. It is neither glass nor normal analcite at present, whatever it may have been originally. It is clear from the analysis, however, that the rock of Shelburne Point and that of The Basin resulted from magmas of almost identical composition.

The original monchiquite (analysis VI) varies somewhat from the others, being higher in alumina, iron and alkalis and lower in lime and manganese. Its alumina must contain considerable phosphoric acid. Its isotropic base, interpreted by Hunter and Rosenbusch as glass, has been shown by Pirsson's recalculation of Hunter's analysis to have practically the composition of analcite.

The plagioclase-basalt of Saddle Mountain is so near to the monchiquite of analysis VI in chemical composition that if its magma had contained 2 per cent. more water it might in all probability have yielded a monchiquite. As many normal basaltic dikes occur near The Basin it seems reasonable to assume that the analcite-basalt magma contained more water at eruption than did those of the plagioclase-basalt dikes.

In the original description of monchiquite Messrs. Hunter and Rosenbusch call attention to the association of all the rocks of that type then known to them with elæolite-syenite, and express the belief that magmas of this kind must have given rise to the monchiquites together with some complementary acid rocks. The expression of this belief in the positive form of the title to

[1] Bull. 107, U. S. G. S., p. 35.

their communication—"Über Monchiquit, ein camptonitisches Ganggestein aus der Gefolgschaft der Elæolithsyenite"—is of course in harmony with the well-known attempts of Professor Rosenbusch to make geological occurrence the foundation stone in the classification of igneous rocks. And whether one believes or does not believe that the "dike rocks" of Rosenbusch have individually or collectively that restricted geological occurrence and that constant association indicating their origin which are assumed in the system of that master, it is of great importance to the development of petrography to know the facts. An association of rocks, the importance of which may be exaggerated from certain standpoints, should not on that account be slighted by those who occupy other points of view.

The analcite-basalt of The Basin occurs in a region where there is a great series of volcanic rocks, mainly andesitic, with basalts, trachytes, and rhyolites, all more or less prominent within five miles of The Basin. Phonolites occur in abundance at and near Cripple Creek, but there seems to be no reason for assuming any relation whatever between the magma of this analcite-basalt and that of the Cripple Creek center. As has been described[1] there are basic dikes at Cripple Creek, some of them plagioclase-basalts and some containing a scanty, colorless, residual material of indistinct character, which was interpreted as nepheline in large part, and hence these rocks were called nepheline-basalts. From the much decomposed condition of these dikes I am unable to say upon reëxamination that they may not originally have contained analcite or a glassy base, but still believe it more probable that they were nepheline rocks.

Since it is evident that the monchiquite or analcite-basalt magma contains nothing peculiar to itself except water, it is difficult to see why Rosenbusch should regard it as a differentiation product of different origin from other basaltic magmas. Nor is it plain why any significance, as to genetic relations, should be attached to the fact that the supposed glassy base of the mon-

[1] Geology of the Cripple Creek District, Colorado, by WHITMAN CROSS. Sixteenth Ann. Rep. U. S. Geological Survey, 1895.

chiquites is similar to elæolite-syenite in composition. The residual parts of any moderately basic rock, after crystallization of the ferro-magnesian constituents, will be identical with some possible extremely feldspathic rock.

As for the question whether the colorless isotropic base of the so-called monchiquites is really glass or analcite it must be admitted that both are possible, although the former has not been proven in any special case known to me. The point raised by Pirsson, however, seems very important, namely, that as the monchiquites are supposed to be rather deep-seated dike rocks, it is much more reasonable to suppose that the residual substance would crystallize rather than form a glass. This argument has special weight where it can be shown that the residue has practically the composition of analcite, and where associated rocks of the same or more silicious composition are found to be holocrystalline.

The name analcite-basalt has been used for the rock here described because it accurately expresses its relation to allied types, because the name has priority over monchiquite through its use by Lindgren[1] for the rock of the Highwood Mountains, Montana, and further because the definition of monchiquite by Rosenbusch implies a glassy base, which is certainly a possibility, so that there may be rocks to which the name monchiquite applies in the sense originally proposed. It is probable that in many cases it cannot be demonstrated whether the colorless isotropic residual matter is glass or analcite, and where decomposed it will be clearly a matter of inference, in most instances. Criteria will doubtless be discovered by which analcite can be more readily determined than at present. The advisable course then seems to be to apply the name analcite-basalt where the determination can be rendered probable and to apply monchiquite in other cases. The fact that an analcite-basalt would have been a monchiquite if its residue had not cystallized shows the extremely close relationship of the two rocks. But it does not follow that

[1] Eruptive rocks from Montana. Proc. Cal. Acad, Sci., Ser. 2, Vol. III, 1890, pp. 39–57 (reference).

all monchiquites would have yielded analcite-basalt on crystallization, for the ratio of $SiO_2 : Al_2O_3 : R_2O : H_2O$ must probably be very nearly 4 : 1 : 1 : 2 in order that this unusual rock constituent may form. With lower silica, nepheline and analcite, or glass, would presumably result.

WHITMAN CROSS.

STUDIES ON THE SO-CALLED PORPHYRITIC GNEISS OF NEW HAMPSHIRE.

CONTENTS.

Introduction.—The following paper embodies the results of some weeks of field work on the New Hampshire terrane, heretofore considered by some writers to be a metamorphosed Archæan sediment, but suspected by others to be eruptive. The conclusions of the author corroborate this suspicion and he has attempted to express them here with the special point in mind. The author desires to express his best thanks to Professor J. E. Wolff, of Harvard University, for valued suggestions and very material aid during the progress of the work.

Historical summary of opinion on the "porphyritic gneiss."—From the conspicuous nature of its outcrops the "porphyritic gneiss" of New Hampshire early attracted the attention of geologists. In the first annual report of the Jackson survey, in 1841, Whitney and Williams, in describing its occurrence remark that "large bowlders of porphyritic granite are very numerous over the sur-

face, from the west parish of Concord to the center of Warner, where we find the rock itself in place. It is a peculiar rock, having large crystals of feldspar uniformly distributed through its mass; they are often glassy, so as to furnish beautiful and striking specimens. This bed of granite extends across the state in a general northeast and southwest direction. It is from eight to ten miles in width, though often interrupted with veins of granite of various texture."[1] With the physical difficulties of a rugged, forest-clad country, it was not to be expected that accurate determinations of boundaries could be made by these geological pioneers. To this fact is due the confusion of the "porphyritic gneiss" and associated schists in the published Portsmouth-Claremont section of the Final Report.

In their section, "from Haverhill to the White Mountains," Whitney and Williams again refer to the formation thus: "From Meredith to Centre Harbor the rock in place is porphyritic granite, often traversed by beds and veins of fine grained, dark colored granite and trap. Some specimens of the porphyritic granite, in which the crystals of feldspar are flesh colored, are very beautiful. . . . . "From Centre Harbor to Plymouth the rock in place is porphyritic granite, traversed by occasional beds of mica slate."[2]

The first distinct mention of the "porphyritic gneiss" in the second (and last) survey of the state, that under the control of Professor C. H. Hitchcock, occurs in the second annual report, 1870. The preliminary map issued with that report roughly outlines the formation which he calls porphyritic granite. He describes it as "common granite full of large crystals of feldspar, generally from one-half of one to two inches long, which gives a checked appearance to the ledges. Some portions of it have evidently been injected, while the arrangement of the feldspathic crystals in parallel lines leads to the suspicion of stratification in other cases. When accurately mapped the area will resemble the trunk and branches of a decayed tree, the

[1] Final Report on the Geol. of N. H., C. T. JACKSON, 1844, p. 51.

[2] Op. cit. pp. 73 and 137.

branches corresponding to the veins which have been injected from the original mass.[1]

In the report for the next year, Professor Hitchcock adopted the view which was held throughout the later publications of the survey. On the map, of a scale of five miles to one inch, he differentiates the Lake Winnipiseogee and White Mountain areas, and gives a brief description of the rock, to which he affixes the name "porphyritic gneiss." He says: "This is an ordinary gneiss, carrying numerous crystals of orthoclase or potash-feldspar, from a quarter of one to two inches long. The longer axes may be parallel to the strike or arranged helter-skelter. It passes into granite with the same porphyritic peculiarity of structure. . . . . We suppose this to be the oldest formation among the mountains. Geologists speak of a rock of this character as common in the Laurentian in various parts of North America and Europe."[2]

At the twenty-first meeting of the American Association for the Advancement of Science, held in 1872, Professor Hitchcock expressly referred the "prophyritic gneiss" to the Laurentian[3] and noted the common parallel structure of the rock which he concluded to be the trace of an almost obliterated stratification.[4]

An indication of doubt as to an exact correlation appears in Professor Hitchcock's "Classification of the Rocks of New Hampshire," published in 1873.[5] He divides the various forma-

[1] Second Ann. Rep. upon the Geol. and Mineralogy of N. H., 1870, p. 33.

[2] Geology of New Hampshire, 1874, Vol. I, p. 33.

[3] Explanation of a New Geological Map of New Hampshire. Proc. A. A. A. S., 1872, p. 134.

[4] Recent Geological Discoveries among the White Mountains, N. H. Proc. A. A. A. S., 1872, p. 135. In this paper the author states his grounds for the correlation, viz., that of lithological similarity between the porphyritic gneiss and the Laurentian of Canada and Europe. At each of the next two meetings of the Association, he reaffirmed his position that there is nothing older in the state than the porphyritic gneiss which was held to be Archæan in age. See Geological History of Lake Winnipiseogee. Proc. A. A. A. S., 1873, B. p. 122, and the Physical History of New Hampshire, *ibid.*, 1874, B. p. 76.

[5] Proc. Bos. Soc. Nat. Hist., Vol. XV., p. 304.

tions of the lower series into two groups — the Laurentian, which he qualifies by an interrogation point, and the Labradorian. The former included the "porphyritic gneiss," Bethlehem gneiss, White Mountain, or andalusite-gneiss, and the breccia of Franconia, in the order of decreasing age. The eight members of the Labradorian "constitute one horizontal series of formations, the lowest resting upon the upturned edges of all the parts of group I." The greater antiquity of the "porphyritic gneiss" than that of the other series "is inferred from the occurrence of several bands of andalusite and granitic gneisses upon both flanks." It is interesting to note that in discussion on this paper Dr. C. T. Jackson declared his belief that "the classification proposed was hypothetical to a great extent, and that sufficient reason for the adoption of the New York nomenclature was not shown."

The first volume of the Final Report of the Hitchcock Survey was issued in 1874. The "porphyritic gneiss" was there explained as the product of altered sediment, the primitive stratified rocks having been metamorphosed in Archæan, or, as then expressed, Eozoic time.[1] The second volume, published three years later, reiterated this opinion, making the terrane the representative of the "first territory in the state that was redeemed from the primeval ocean."[2]

"A porphyritic, or augen-gneiss, is eminently characteristic of the fundamental rocks in every part of the world, and hence ours may readily be called Laurentian."[3] A still closer correlation was suggested whereby the "porphyritic gneiss" of the White Mountain district, and inferentially that of the whole state, was put in the "upper division of the Laurentian system, as it is developed in Canada and New York."[4] In the general résumé of the stratigraphical relations, a thickness of five thousand feet was estimated for the formation. With it was included the "younger Bethlehem and Lake Winnipiseogee gneisses to form the whole Laurentian, aggregating 34,900 feet in thickness.[5]

[1] Geol. of N. H., Vol. I., 1874, p. 512.
[2] Geol. of N. H., Vol. II, 1877, p. 519.
[3] *Ibid.*, p. 668.
[4] *Ibid.*, p. 252.
[5] *Ibid.*, p. 668.

From this brief review it is seen that the placing of the "porphyritic gneiss" so low in the geological scale was largely due to the prevalence of two pernicious doctrines then held in the study of crystalline schists. The application of the "lithological canon" was a constant feature in the efforts of the second survey to work out their difficult field. The coarse granitic gneisses, the augen-gneiss, and the andalusite-gneiss were each supposed to be represented in the typical Laurentian of the better known regions, thereby establishing synchrony. Again the distinct foliation in many parts of the "porphyritic gneiss" led to the other serious error of considering the rock as a metamorphosed sediment, which still preserved traces of its original planes of stratification.[1] This position being taken, it was but natural to look for structural relations with the surrounding formations, and at many contacts, the greater antiquity of the porphyritic rock would often appear evident. Needless to say, however, in the light of present knowledge, that all such reasoning is without foundation so far as it refers to large isolated areas of thoroughly crystalline schists. Thus the character of the terrane had to be determined by other methods. The latter were very sparingly used by the survey, and consequently its final conclusions assigned to the "porphyritic gneiss" the very important position of a foundation member in the entire geological series.

The interpretation of other terranes was, of course, greatly influenced by this fundamental idea. The survey fixed the geological position of the Bethlehem gneiss,[2] and of the Montalban group and the Lake Winnipiseogee gneiss [3] directly by reference to the "porphyritic gneiss," and the later succession was correspondingly affected. In fact, Professor T. Sterry Hunt's conception of and nomenclature of the Montalban group was founded on the conclusion that there is this demonstrable Laurentian in New Hampshire.[4]

[1] Geol. of N. H., Vol. II, p. 99.

[2] 1871. See Geol. of N. H., Vol. I, p. 34; Vol. II, p. 452.

[3] *Ibid.*, Vol. II, pp. 564,662.

[4] Geol. Mag., 1887, p. 1499; Nature, Sept., 1888, p. 521.

We have already referred to some hints of an igneous, intrusive origin for the "porphyritic gneiss," that were given by the survey officers. Similar suggestions appear in many parts of the different reports.[1] The facts described in these passages were supposed to be explained on the metamorphic theory as being characteristic of only those parts of the ancient stratified rocks which had been altered to the extent of complete fusion.

In his address as vice president of section *E* of the American Association in 1883, Professor Hitchcock expressed some modification of his earlier opinions on the origin of the porphyritic gneiss. He said: "A careful study of the crystalline rocks of the Atlantic slope indicates the presence of scattered, ovoidal areas of Laurentian gneisses. Those best known have been described in the geology of New Hampshire. Instead of a few synclinal troughs filled to great depths with sediments, the oldest group is disposed in no less than twenty-two areas of small size, scattered like the islands in an archipelago.[2] There are no minerals in these Laurentian islands that do not occur in eruptive granite; and the schistose structure is often so faint that the field geologist need not be blamed if he acknowledges his inability to detect it. Likewise we discover the same fluidal inclusions and the vacuoles that pertain to granite."[3] Comparing these islands to volcanic oceanic islands of the present day, he suggests that the foliation of the porphyritic gneiss may be the result of the superposition in quaquaversal sheets of lava about each volcanic cone, aided by flows of mud and wear by water between igneous flows. In this way we might have a "concentric statiform arrangement in the whole mass." Subsequent metamorphism by heat and pressure would lead to the development of new minerals in foliated beds.

The next important notice of this formation appears in Whitney and Wadsworth's "Azoic system."[4] They instituted a close

[1] See Geol. of N. H., I, pp. 27, 33; II, pp. 102, 472, 520.

[2] Proc. A. A. A. S, 1883, E., p. 186.

[3] Op. cit., p. 187.

[4] Bull Mus. Comp. Zoöl., Harvard College, Vol. VII, 1884, p. 383 ff.

criticism of the general methods of the New Hampshire survey, and looked with especial disfavor upon the liberal use of the "lithological canon," as accepted by the members of that survey. A convenient résumé of the various classifications proposed for New Hampshire rocks is given in tabular form at page 396 of the memoir. The possibility of an eruptive origin for the "porphyritic gneiss" was remarked by the authors.

In 1884 Professor Hitchcock stated that "all thoroughly crystalline series of the Atlantic region are of Eozoic age."[1] Two years later he edited the "Geological Map of the United States," in which the "porphyritic gneiss" is colored as Laurentian.[2] A somewhat full account of his opinions on the formation was given in a paper on the "Significance of Oval Granitoid Areas in the Lower Laurentian,"[3] from which it is evident that in 1890 Professor Hitchcock held practically the same views on the present subject as those which he published in 1883.

While the present paper was in process of preparation the last word on the formation was given by Professor Hitchcock in this JOURNAL. After tracing in a general way the history of geological surveying in New Hampshire, he makes the following significant statement of a changed point of view: "The question now arises, how can our early classification [of the rock series] be improved? It is eighteen years since the New Hampshire report was published, and there are many new workers in the field, all placing great reliance upon petrographical principles, such as were inaugurated in Dr. Hawes' report. Some are advocates of extreme metamorphism, and hence the conclusions are not harmonious. It seems to us that our early views may be modified by the following principles: (1) The mineral characters of crystalline rocks are not a sure guide to geological age. (2) Protogenes, diabases, and diorites, more or less interstratified with hydro-micas, are of true igneous origin. (3) The

[1] Trans. Am. Inst. Min. Eng. XII, 1884, p. 68. Cf. a paper in Proc. A. A. A. S. of the same year (p. 396) where he again holds the porphyritic gneiss to be Laurentian.

[2] Trans. Am. Inst. Min. Eng., Vol. XV, 1886, p. 465.

[3] Bull. Geol. Soc. Am., I, 1890, p. 557.

Archæan gneisses and protogenes may also be of igneous origin, and their apparent stratification has no connection with sedimentary or chemical deposition, etc. . . . . Applying such principles to the classification of the rocks of northern New England, we may improve on the report in several particulars. (1) Archæan rocks are not eliminated from our list. They exist as oval areas, such as have been indicated in the Stamford gneiss, and south of Mount Killington, Vt., in the Hinsdale, Mass., area, the Hoosac Mountain, and elsewhere. I recognize the porphyritic gneiss in the Stamford rock, and in the Hoosac tunnel as Archæan. (2) Our hesitancy about the place of the Bethlehem gneiss is met by recent observations. They are batholites, containing inclusions of the adjacent mica-schists. It does not follow that all these protogene areas are of the same character; each one must be studied by itself."[1]

However satisfactory such conclusions may be in their appli cation to most of the formations in the state, a clear statement of the true relations of the porphyritic gneiss has not yet been made. The author's recognition of the correct methods which must be used in interpreting crystalline schists has as yet not been supplemented very largely by their positive exercise in the field, and the implication in the foregoing extract that the Archæan appears in the state in "oval areas," either igneous or non-igneous, is still without demonstration.

We shall hereafter adhere to the name porphyritic granite, for the rock under discussion instead of porphyritic gneiss which has been so far used. As will appear later, the former name, while not embodying all the generalized features of the rock, is preferable to the official one of the second geological survey.

Geographical distribution.—The porphyritic granite, as shown on the survey maps, occupies four large areas with several smaller ones. Of these the largest one extends from Mount Monadnock, N. 5° E. to the northern flank of Cardigan Mountain, a distance of sixty miles; while it varies from three to

[1] The Geology of New Hampshire. JOUR. GEOL., Chicago, Vol. IV, 1896, p. 57.

twelve miles in width. Since this occurrence covers more than four times as many square miles as any other, it may well be called the "Main area." Associated with it in Sullivan, Merrimack, and Hillsboro counties, are some half dozen much smaller outcrops of the same rock which are surrounded by schists, and are thus outliers from the larger mass. Twelve miles west by south of Mount Monadnock, a second important mass of regular elliptical or oval-shape cuts cross the Ashuelot division of the Boston and Maine railroad. The longer axis runs north and south, and is about ten miles long, while the shorter, transverse to the former, is six miles long. From the village of Ashuelot, situated on porphyritic granite, we shall derive a distinctive name, and call this the "Ashuelot area." The survey has mapped a large "White Mountain area," which is distributed in irregular elongated form at the north of the Main area from Mount Stinson to Mount Lafayette. Some twenty miles long, it also varies considerably in width, being only a mile wide near the Profile House, but broadening out to six miles at the Kinsman Notch. From there a long tongue of the rock runs southerly down the valley of the Pemigewasset River. The strike of this area is like that of the Main area, a few degrees east of north. Following the common axis of both areas northward from the Profile House, a small but important "Littleton area" of some eight or ten square miles in extent, appears near the town of Littleton. The fourth widespread occurrence of the porphyritic granite is found in another irregular mass thirty miles long, and from one to eight broad, running parallel to the Main area from Laconia to Waterville. This may be referred to as the "Winnipiseogee area," from its proximity to the beautiful lake of that name.

The very local outcroppings of this rock in other parts of the state are in point of size insignificant, but they are of value in helping to determine the relations of the whole formation. Notable among these are the small patch on the top of Mount Prospect west of Squam Lake and the long dikelike mass north of New Boston in Hillsboro county. The grounds for coloring in the mass of porphyritic granite at the southeast base of Mount

Monadnock did not appear to be corroborated by the present writer in a somewhat careful study of that region. The mantle of glacial drift is there very heavy, but the few outcrops which were discovered seemed to prove the bedrock to be of the same nature as the schists round about. Again, a visit to Mount Osceola showed that the area of porphyritic granite plotted on the survey map as occurring on its southern side is really occupied by the same coarse-grained hornblende-granite which occurs in the bed of Mad River, the "Conway Granite" of the survey.

So great being the extent of the formation, it was impossible in the time at the disposal of the writer to make a close examination of all parts of the porphyritic granite. Accordingly, most of the observations in the following pages refer to three areas, the study of which promised to be most fruitful in the problem before us. Those selected were the Winnipiseogee area, the Ashuelot area, and the contact of the Main area from the town of Jaffrey to Henniker on the Peterboro and Hillsboro branch of the Boston and Maine Railroad. We shall consider these areas separately, treating of the geological results obtained in each along with certain other facts whose arrangement would be difficult by any other method of discussion.

Brief description of the porphyritic granite.—General macroscopical descriptions of the granite are given in several parts of the "Geology of New Hampshire." The rock is remarkably simple in its phasal differentiation; so far as a considerable collection shows, there are only two important variations in it throughout its whole extent. It may be either a porphyritic granitite or a porphyritic granite proper, and either of them may have the foliated structure. They pass into each other by insensible gradation in all the areas and it seems to be impossible to map them separately. With the exception of this and a few other variable features noticed in the sequel, the porphyritic granite is essentially uniform; it is thus possible to dismiss its characterization in a comparatively summary manner. In a future paper, the author hopes to give an account of certain

petrographical features whose description here is not rendered either advisable or necessary for our present purpose.

The name "porphyritic granite" for this rock is regarded as the best available one both on the ground of inherent meaning

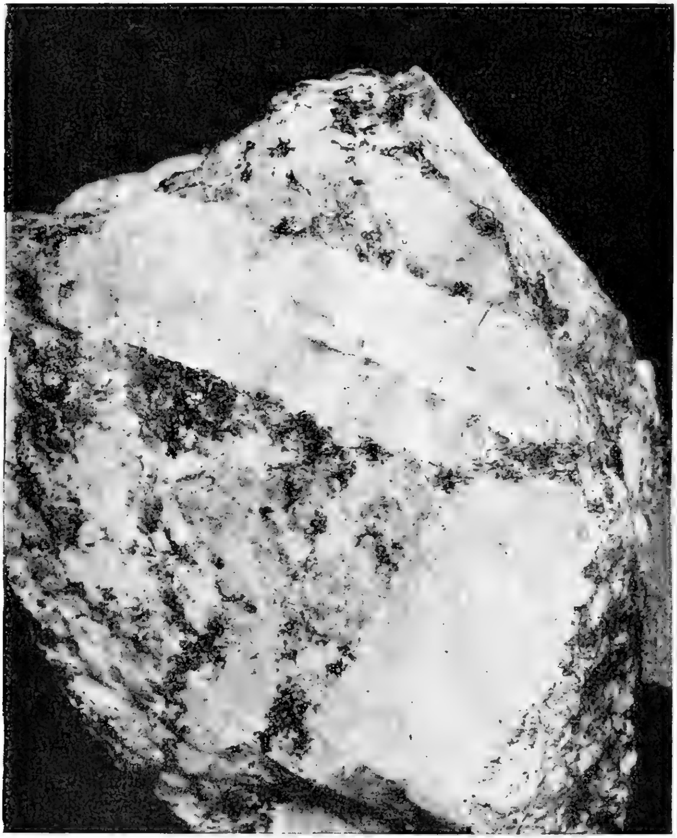


FIG. 1.—Photograph of a specimen of the porphyritic granite—obtained near New Hampton Centre—illustrating general habit of granitic phase, twinned phenocrysts, etc.—about natural size.

and of precedent. The composition and order of crystallization make it a true granite rather than a gneiss although the pseudo-schistose structure is so generally present. For very similar rocks, the names "granite-porphyry," "gneissic granite," etc.,

have been employed. It seems best to use the original name at first used by each of the New Hampshire surveys and in this we follow the nomenclature of Lehmann, Sederholm, Gümbel and others who have dealt with very similar rocks.

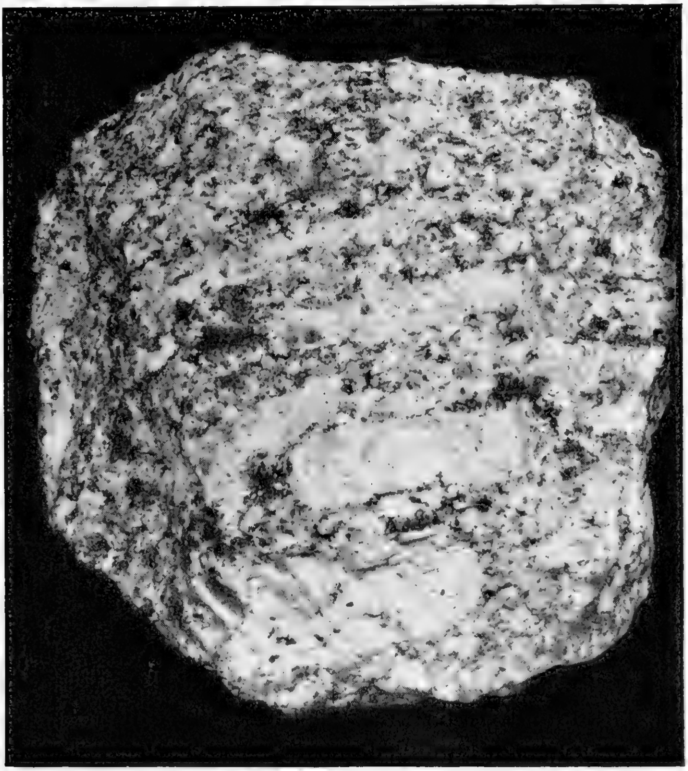


FIG. 2.— Photograph of a specimen of the porphyritic granite, showing a foliated phase near Hancock Station. The lowest phenocryst displays two prismatic partings besides the normal cleavages, parallel to *P* and *M*. The base is nearly in the plane of the paper. About one-half natural size.

The granite is always striking and handsome in appearance The groundmass is a coarse-grained, light to dark gray, granular aggregate of quartz and feldspar interspersed with flecks, blotches and lines of greenish muscovite and brilliant brown biotite.

Within are embedded the lustrous phenocrysts which generally, though not always, lie in the foliation plane when the rock has the plane-parallel structure.

The phenocrysts are glassy to opaque white and seem to be in every case either orthoclase or microcline, which may be intergrown with another (triclinic) feldspar in the usual microperthitic fashion. The largest ones are as much as twelve centimeters long. The usual habit is that of simple Carlsbad twins. They present straight edges to the surrounding matrix, giving the planes (001) (010) (110) and (101). This idiomorphic appearance is often lost in the slide through the great amount of resorption and marginal corrosion. Occasionally small shreds of biotite, a minute individual of apatite, or a few grains of quartz may appear in the core of the feldspar, but as a rule it is notably free from primary inclusions. The results of decomposition are normal. The changing to a reddish hue is common in some weathered phases.

The matrix of the rock is simply a typical coarse granitite on the one hand or a granite proper (in the classification of Rosenbusch) on the other, in either case with or without the foliated structure. The feldspars have the same general characters as those of the earlier generation except that a triclinic feldspar, probably andesine, now appears as an independent constituent. Quartz, biotite and muscovite constitute the other essentials. Large but relatively few individuals of magnetite, titanite, apatite and zircon are accessory. The quartz and feldspars are roughly equidimensional with diameters becoming as much as a centimeter in length; in fact the feldspars are often transitional into the phenocrysts. Quartz very often crystallized simultaneously with the feldspars resulting in the formation of a true micropegmatite which is extremely common in slides of the granite from all the areas. It is best shown in specimens collected along the railroad from Hinsdale to Ashuelot. There can be little doubt that the structure is primary in the formation as a whole. It is possible, however, that in zones of stress the development of the structure has been aided by the meta-

morphic cause of crushing, as described by Howitt, Hobbs and other writers.

The proportions of phenocrysts to matrix and of acid to basic constituents are quite constant in the porphyritic granite. The latter relation is that usually found in most highly acid granites. Now and then, a well-foliated segregational mass of biotite, quartz, much titanite and apatite, wrapping about phenocrystic cores of feldspar, may be encountered. Again, a phase of the rock nearly devoid of phenocrysts is not rare, although quantitatively it is insignificant as compared with the porphyritic phase. Both of these variations from the type will be discussed in what follows.

Field relations: The Winnipiseogee area.—The general distribution of the porphyritic granite in the Winnipiseogee area is described at length in "The Geology of New Hampshire."[1]

The topography of the area is, on the whole, not of a very definite nature. The greater reliefs, which vary from 800 to 1500 feet above sea level, are without distinct trends, and are the forms which might be expected as the result of eroding a massive rock of pronounced homogeneity. Upon this rolling ground the glacial drift has been deposited in unusual thickness, especially in the southern half of the area, where the hills are commonly composed of washed drift and till. Correlative with glacial reliefs are the glacial depressions seen in the numerous lakes and ponds which make such picturesque variety in the landscape of Carroll county. These modern deposits make it difficult to work out the relations of the bed-rocks. The variety of outcrops in many parts renders the determination of contact lines almost impossible, and it is largely to this cause that the suppositional nature of some of them is due.

The geological relations of the Winnipiseogee area.—The survey map places the porphyritic granite of this area in contact with the Lake Winnipiseogee gneiss, the Montalban group of schists, the Rockingham mica-schist, and the various eruptive masses of Waterville. For convenience we shall briefly indicate

[1] Vol. II, p. 592.

the facts of field observation which have been adduced in connection with each of these formations.

The porphyritic granite in contact with the Lake Winnipiseogee gneiss.—Close by Gilford Station, on Smith's Neck, the boundary line of the porphyritic granite and the Winnipiseogee gneiss appears, and, so far as known, this is its most southerly extension in this district. It is a typical acid biotite-gneiss at this place, elsewhere muscovite may be found. A few of the outcrops are significant. Here and there in the porphyritic granite masses of rock very similar to the main body of the schist occur in a horselike relation, although nowhere could the actual contact be found, and thus render possible a proof of that derivation of the masses. On Governor's Island, two miles to the westward, a large outcropping of a coarse muscovite-biotite-gneiss occurs. This is a typical representative of the Lake Winnipiseogee gneiss, and this mass is completely surrounded by porphyritic granite for a distance of at least a quarter of a mile in all directions. About that distance from this outcrop of schist, the real contact of the porphyritic granite and Lake Winnipiseogee gneiss was found, and it became evident that in the first occurrence we had to deal with an outlier removed by some means from the parent schist terrane. This relation could hardly be explained except on a hypothesis of the igneous intrusion of the coarser rock in which the schist was enclosed as a great horse. The truth of this supposition was strengthened by the discovery of two marked apophyses of the porphyritic granite running into the inclusion. Returning to the molar contact, a corroboration of our conclusion from a study of the outlier appears in a clearly defined tongue of the porphyritic granite which can be traced for some distance into the schist. Whereas on Smith's Neck the porphyritic granite was largely granitic, here a well-defined foliation characterizes the rock. The strike of the foliation planes is N. 3° E., and the dip is 82° to the east. It is noteworthy that the strike and dip of the schistosity in the adjacent schist is the same. In other words, there is an apparent conformity between them. At several places among the numerous outcrops of porphyritic gran-

ite on the island, very coarse pegmatitic dikes appear which are similar to the granite, and do not appear to belong to the class of pegmatite veins of segregational origin so common in the crystalline area of the state.

About a mile and three-quarters from Weirs there is a small inlet, on the south side of which the porphyritic granite is in contact with a dark coarse-grained gneiss. This seems to be equivalent to the Lake Winnipiseogee gneiss. It is cut by an apophysis of the porphyritic granite, and a horse of the schist can be seen on the bare ledges enclosed within the other rock. Again, as on Governor's Island, there is an apparent conformity of position.

Just across Meredith Bay, on Spindle point, an interesting contact occurs. The porphyritic granite outcrops occasionally on and about the road from Meredith with pretty definite foliation, the strike varying from N. 20° E. to N. 40° E., the dip high, but changing from easterly to westerly in an irregular fashion. On the top of the hill at which the road ends, an solated mass of another rock is conspicuously displayed in the well-smoothed ledges. It is dikelike in its form, being fully four hundred yards long and from ten to twenty wide. There is a distinct schistosity with its planes parallel to the longer axis of the mass which strikes S. 40° W. The dip is high at about 75° to the southeast, making an apparent conformity with the enclosing porphyritic granite, which is here well foliated. Within a distance of 300 yards south of this long band, and oriented with the longer axis parallel to it, smaller bodies of the same rock occur, again completely enclosed by porphyritic granite. They have the same pronounced structure-planes with a similar relation to the foliation of the country rock. From the hill top the largest of all these parallel bodies strikes toward a larger body of the same rock. Like the other, this mass is characterized by a strong gneissic structure. It also possesses an elongated form. We have here to deal with a number of horses immersed in a once molten magma which chrystallized out as porphyritic granite. The patent differences of grain and

structure, the sharp boundary between the two rocks, the irregular thinning and thickening along the length of the inclusions, all point to this belief. Here and there, within their boundaries, obscure apophysal extensions of the coarser rock may be observed. But this conclusion reaches practical certainty when the molar contact of the porphyritic granite and the "Lake Winnipiseogee gneiss" is studied. The latter is seen to be precisely the same coarse-grained biotite-gneiss as that in the inclusions, except for certain differences which can be explained as due to exomorphic change wrought by the porphyritic granite. Apophyses of the latter may be seen at the neck or isthmus of the peninsula cutting the gneiss. An important relation subsists between this line and the arrangement of horses on the hill. Not only are they parallel to one another, but they lie parallel to the line of molar contact.

Transition zone at Centre Harbor.—At Centre Harbor the gneiss lies on the east side of the boundary and at some distance from it is the usual coarse-grained muscovite-biotite rock of the Lake Winnipiseogee gneiss terrane. Its foliation planes strike N. 15° W., and the dip is about 60° easterly. As one approaches undoubted porphyritic granite through a distance of fifteen feet from the contact, one notes the large orthoclase and microcline feldspars two inches long, which normally are confined to the porphyritic granite, now scattered through the finer-grained rock with their longer axis parallel to its schistosity. They grow more numerous as the porphyritic granite is neared, until finally some four or five yards from their first appearance, the outcropping rock is typical porphyritic granite. It possesses the same strike and dip as the gneiss, being well foliated. There is thus a complete and slow graduation of the one terrane into the other, making it impossible to draw any line between them.

Transition zone near New Hampton Station.—A similar zone of transition between these two terranes occurs a mile and a quarter from New Hampton Station on the road running southeast from the station. The zone of passage is here much wider

than at Centre Harbor, but the properties of its magmalike gneiss with the sprinkling of large porphyritic crystals of feldspar are identical with those of the other locality. As a rule, there is a sharp contact between the porphyritic granite and the invaded rocks, like that which in general characterizes plutonic bodies. These belts of transition have at first sight a puzzling appearance. That they are, in reality, eruptive contacts seems, however, to be unquestionable. Durocher long ago noted such an intimate union along the boundary of gneiss cut by stock-granite. He considered the temperature of the igneous rock in such instances sufficiently high to produce a melting up of the gneiss the "particules" of which "ont dû posséder une assez grande mobilité, et cristalliser à peu près dans les mêmes conditions que les molécules du magma granitiques.[1] In his "Geog. Beschreibung Bayerns,"[2] Gümbel speaks of there being numerous transitions from "bunter gneiss" to "bunter granit" which cuts the former. Michel-Lévy has very clearly discussed the phenomenon in general. He says:[3] "C'est ici le cas de remarquer que lorsque deux grandes masses de roches acides se touchent, le plus souvent elles se trouvent réunies par une zone de passage plus ou moins puissante, dans laquelle les caractéres pétrographiques des deux roches sont, pour ainsi dire, confondus et mélangés.[4] In the same paper from which this quotation has been taken, the author cites many examples of such transition, among which that from granite to gneiss[5] and that from granite to "micro-granulite" may be especially mentioned. He explains them as due to an impregnation of the older rock by "les éléments fluides en voie de dégagement" from the igneous rock. When the temperature and pressure are suitable, a part

[1] Mém, de la Soc. Géol. de France, 2e sér. t. VI, p. 47.

[2] Abtheil. II, p. 272.

[3] Bull. de la Soc. Géol. de France, 3e sér., t. VII, 1878–9, p. 852.

[4] Cf. Ch. Vélain, Conférences de Petrographie. Paris, 1889, p. 6.

[5] Cf. LEHMANN, Untersuch. über die Ent. der alt. kryst. Schiefergesteine, p. 76. GREGORY, Q. J. Geol. Soc., 1894, p. 260 ff. BARROW has noted a complete amalgamation at the contact of granitite and diorite, of which the former is the intrusive member, Q. J. Geol. Soc., 1892, p. 121.

of the constituents of the older rock will become mobile and will tend to assume the same structure as those of the second period of consolidation in the younger rock.

McMahon pointed out how difficult it was to explain the presence of zones of transition about the Dalhousie granite of the Himalayas in some places and their absence in others on the old metamorphic theory of the central gneiss. He favored the opinion that, whether a zone of passage characterizes the contact or not, depends on the closeness of mineralogical similarity between the Dalhousie granite and the invaded strata. Only in places where the latter had been regionally metamorphosed did he find the appearance of gradual change from the granite into the country rock. The transition zone described by Lawson between the Laurentian gneiss and hornblende-schist in Rainy Lake region is so similar to the zones of the porphyritic granite that it will be well to read his own words on the subject: "Within the hornblende-schist, distinctly recognizable as such, there may occasionally be detected large crystals of red feldspar, which is quite foreign to these rocks, as if the feldspathic magmas had penetrated within the schist and crystallized there in the same large crystals in which they are wont to appear in the coarse gneiss."[1]

These authentic determinations of transgressive junctions between plainly eruptive rocks and their respective country rocks, coupled with the expectation that they should appear in contacts of that nature, lead us to follow Gregory [2] in concluding that they may form a useful criterion for a decision on an eruptive origin for massive rocks. So far as this principle is concerned then, the porphyritic granite can be eruptive.

The foregoing description of contact phenomena seems to us to indicate that the porphyritic granite has been intruded into the schistose rocks which have been grouped together in the terrane of the Lake Winnipiseogee gneiss by the survey. This conclusion is forced upon one as well in the study of the northern

[1] Ann. Rep. Geol. Surv. Canada, 1887–8, Part. F. p. 33.

[2] Q. J. Geol. Soc., 1894, p. 262.

extension of the "fishhook" as in the southern part to which attention has been so far called.

The porphyritic granite in contact with the Montalban group of schists.—We shall not consider in this place the grounds on which the survey has separated the Lake Winnipiseogee gneiss from the Montalban group. Our field observations have shown us pretty clearly that, although the lithological characters of the two terranes may be on the whole different, any distinction between them from a supposed difference of age is as yet without demonstration. Be this as it may, the problem before us can be solved without either proof or disproof of such a contention. At many points along the contact, the schists of the Montalban group are intersected by apophyses from the porphyritic granite, and appear as inclusions in the latter rock. The evidences of an intrusive origin for the porphyritic granite are of the same nature as in the case of the Lake Winnipiseogee gneiss, and are just as conclusive.

The Montalban group and porphyritic granite come in contact along the line running from Long Bay to Great Bay, and about one half mile east of Great Bay. Here a number of well-marked horses of the neighboring Montalban gneisses occur in the porphyritic granite. They possess a thoroughly gneissic structure, being as well foliated as their parent mass less than a hundred yards away. In this case the horses are not elongated and do not show any definite relation of position, either to one another or to the main contact line. Apophyses of porphyritic granite were also discovered along this part of the boundary.

An interesting occurrence of the gneiss appears in the road on the north side of Shaw's hill. It is isolated and completely surrounded by porphyritic granite whose nearest molar contact is nearly a mile away. This great horse is highly schistose, and several tongues of the granite here and there cut across the structure planes. The development of garnets in the horse may hint at some degree of contact metamorphism.

A second large horse which is some distance from its parent

terrane outcrops one mile and a half north of Holderness on the upper road. Here a gigantic slice of the country rock, about sixty feet wide and three hundred feet long, has been floated off and rests with its longer axis north and south, *i. e.*, parallel to the molar contact. It is composed of the usual biotite gneiss in which a thick sheet of hornblende-gneiss lies embedded, making up most of its mass. The latter has itself the appearance of being an eruptive rock which is thus older than the porphyritic granite. Associated with it are a large number of smaller biotite gneiss fragments which have no definite arrangement, but make a confused medley of discreet masses in the porphyritic rock. The whole looks like a huge flow breccia. Rather more than a half mile further north on the same road, there is a breccialike aggregation very similar to the last, even to its containing hornblende-gneiss folded up in a large mass of biotite-gneiss.

Three hundred yards west of where Dr. Dana's road leaves the four corners at New Hampton Centre we note another of those zones of transition between the porphyritic granite and the schists in contact with it. It is some twenty feet wide, and is strikingly similar in appearance to the case already described at Centre Harbor. Here the schist is cut by intrusive tongues with more or less sharp boundaries. These apophyses run across the gneissic planes.

On the extreme eastern end of the Sandwich Mountains at an elevation of about seven hundred feet above the Bear Camp River, a remarkable flow breccia or "permeation area"[1] outcrops in some extensive pasture fields. The rock presents all the features of a plutonic flow. The horses are here almost entirely hornblende-gneiss, some of them massive, both fine-grained and coarse-grained, others distinctly schistose. The porphyritic granite is on the whole granitic in appearance, but at the boundaries of the fragments, the feldspar phenocrysts are often oriented about them in a way which is strongly suggestive of a flow structure. The usual trendless nature of its constitu-

[1] Barrow, Q. J. Geol. Soc., 1893, p. 331.

ents is also lost in some of the tongues of porphyritic granite which penetrate the fragments in all directions. There the minerals are pulled out in planes parallel to the walls of the intrusion. The source of the hornblendic inclusions was discovered within a hundred yards of the breccia. An unknown thickness of the hornblende-gneiss lies interbedded in the biotite-gneiss. This great breccia outcrops at several places through a distance of three hundred yards along the base of the mountain and is only one hundred yards from the massive terrane of the Montalban group, which is continuous all the way from Morgan Mountain.

These occurrences of hornblende-gneiss in the porphyritic granite throw light upon the "hornblende rock" which was noted by Hitchcock in the Survey Report[1] as occurring to the east of Wickwas Pond. It covers altogether about an acre in extent. The rock is a hornblende-gneiss closely related in composition to the masses already described. It has a strong schistosity which lies parallel to the foliation of the granite enclosing it. The latter sends intrusive tongues into the gneiss which is evidently a large floe of the country rock moved far from its original source.

The small oval area of the porphyritic granite on the top of Mount Prospect is a stocklike body which suggests from its position an intrusive origin. Field study confirms this opinion. The rock is typical of the porphyritic granite in composition, in grain, and in the size of the phenocrysts. Within this porphyritic granite there are embedded several horses of the surrounding Montalban schists. The latter are extensively crumpled, perhaps by the intensity of the granitic intrusion. Again one can notice the parallelism of the phenocrysts to the margins.

The porphyritic granite in contact with the Rockingham mica-schist.—One of the most important localities in the state to suggest an intrusive origin for the porphyritic granite is on Saddle Hill, where that rock comes in contact with the Rockingham mica-schist. Here the formation is composed of well-

[1] Vol. II, p. 594.

foliated, fine-grained, muscovite-biotite-schist with abundant mica. The molar contact is found on the eastern end of the hill. It strikes N. 25° W., and is parallel to the schistosity of the mica-schist and to the pronounced foliation of the porphyritic granite. All the structure planes dip westward at a high angle. Going across the strike from the contact toward the porphyritic granite a remarkable series of elongated horses of the schist interrupt the continuity of the granite. They are usually much longer than their width, as, for example, a large one 150 feet long by 35 feet wide, which appears on the west side of the saddle. In most cases there is a definite orientation of the horses parallel to the contact line, while the foliation of the porphyritic granite wraps around the inclusion in a significant way. They are uniformly schistose with that structure as well developed as in the main body. Crumpling of the horses is also characteristic. For about two hundred yards east of the contact, the schist is cut by several intercalated sheets of porphyritic granite, varying from five to ten yards in thickness. Their phenocrystic feldspars lie parallel to the walls between which the sills were intruded. Similar sheets can be found in the pasture on the southern flank of the hill and west of Randlett Pond.

Relation of the porphyritic granite to the Waterville eruptives.—It is probable that the porphyritic granite is older than all of the intrusive rocks of the Waterville Mountains. The contacts were discovered in only one place, namely, on the southern slope of Mount Whiteface; there the hornblende-granite composing the mountain distinctly cuts the porphyritic granite. In the path from the Elliott House, at Waterville, to the top of the Sandwich Dome, many outcrops of several types of granitic rocks present a problem of correlation which the writer has had no opportunity to solve. It is possible that these rocks are chilled phases of the Conway granite; for there is, in the main, a tendency towards a porphyritic structure throughout, which on the one hand becomes more pronounced as one approaches the porphyritic granite, and is entirely lost in the very coarse Conway

(hornblende) granite in the bed of the Mad River. If this hypothesis be correct, the Conway granite is younger than the porphyritic granite, for at about 1800 feet above the river the porphyritic phase distinctly cuts the coarser rock.

The Ashuelot area.—The country rock about the porphyritic granite of the Ashuelot area is referred by the survey to three different formations. the Bethlehem gneiss, the schists of the Coös group and the Montalban group. Specific reference to this area was made in the second volume of the Survey Report.[3] In

[3] P. 470.

their general correlation, the survey considered the markedly oval form of this and other occurrences of the porphyritic granite as allying it in point of age to similarly shaped masses in the Archæan elsewhere. Such a form has a nearer homologue to the batholites described by Emerson in western Massachusetts, and as we shall see, these similar forms have similar origins. That the porphyritic granite of the Ashuelot area is eruptive and of an intrusive nature can be amply proved. We shall not attempt to trace the evidence from the contact-phenomena, as it might be traced in a complete description of the whole boundary. It is of the same nature as that outlined for the Winnipiseogee area. With that fact in mind, we have considered it expedient to refer to a few only of the possible localities which can be readily visited for confirmation of our views.

A representative contact of the porphyritic granite and Coös mica-schist outcrops where the boundary line between them crosses the road running southwest from Ashuelot over Gun Mountain. Here and along the western ridge of Gun Mountain the typical biotite-muscovite-schist is strongly charged with interbedded actinolite-schist and quartzite. Several apophyses of the porphyritic granite cut the schist. One of them, twenty feet wide, cuts across the strike, extending a considerable distance from the contact before it disappears under the soil-cap; another over two feet in width is also well exposed, but lies nearly in the planes of schistosity. Horses of schist are embed-

ded in the granite, but the overlying loose deposits prevent the discovery of any definite arrangement among them. The granite itself has a good parallel structure, and it is important to note that its structure-planes are conformable in strike and dip with those of the adjacent schists. This same conformity was several times observed along this western side of the area. Sometimes, even at the contact, the porphyritic granite is quite granitic without a trace of the foliated structure. A good example of this appears at the contact on Hall's hill, near Chesterfield factory. At this locality, too, there is no doubt as to the relation of the two formations. The intrusive tongues of porphyritic granite cut across the schists and associated gneissic bands in a very marked way; the sharp contrast of grain and composition enabling one easily to differentiate the igneous masses. Occasionally dikes of the porphyritic granite may be found traversing the schists at a distance from the contact. At the three corners, about a mile south of Chesterfield, numerous great veins of coarse pegmatite outcrop and with them occurs a set of true porphyritic granite dikes which are probably apophyses of the main mass, half a mile away.

Facts of like character refer to the contact with the Bethlehem gneiss on the eastern side of the oval. Field evidence shows that the latter is of the same metamorphic epoch to which the Coös mica-schist is referred; thus, the argument regarding the better exposed part of the boundary applies to it in its entirety.

Fitzwilliam area.—We have seen already that the survey suspected an eruptive origin for certain parts of the porphyritic granite, and had cited facts from the Fitzwilliam area as in part the basis for the conception. The contact line of this little patch of the rock is very clear in its teaching. Even more graphic than that of the bowlders described in the survey report[1] is the evidence where the rock is in place. About a mile southwest of the village the porphyritic granite is found in a pasture field by the roadside. Included in it are many horses of biotite-

[1]Vol. II, p. 471.

gneiss, some of which are large, being as much as twenty-five feet in diameter. Within one of the latter an interesting irregular injection of the porphyritic granite is well exposed. One feature exceptionally well shown is the fine-graining along the margins. At this place, too, dikes of the Concord granite cut the porphyritic granite, and the former rock is thus the youngest terrane in the region. Since it surrounds the porphyritic granite on all sides, this Fitzwilliam occurrence may itself be a large floe brought up from below from a much larger mass.

The Main area.—Our observations on the Main area were extended only to its southern half. The great thickness of the various glacial deposits make it, on the whole, less satisfactory for a study of contact relations than the Winnipiseogee area. We have aimed in the course of a somewhat hasty examination to discuss the facts as regards the schists grouped by the survey under the names of the "Ferruginous slates," and the "Ferruginous schists." In both, the rocks consist of two-mica-schists, biotite-schist, biotite-gneiss, and muscovite-biotite-gneiss, all of which may be garnetiferous. Between them we can trace no definite distinction, either of composition or of age, and the area on the eastern border, marked "Lake Winnipiseogee gneiss," encloses stripes of schistose rocks which are identical with those of the above-mentioned groups. Here, as often elsewhere, the grounds for the subdivision carried out by the survey do not appear in the field.

The great sill of porphyritic granite to the north and northeast of Greenfield has one contact well exposed with interruptions for the distance of a mile. It is an intrusive one. The granite was erupted into the schists along a plane of foliation, and there is the usual development of parallel structure in many of its outcrops which accords with that of the walls. The intrusion is, on the whole, sheet-like in its form, though in some places where the schists are intensely folded, it cuts across their structure-planes. In such cases the foliation of the porphyritic granite remains parallel to the boundary line. The apophyses penetrate the schists irregularly in all directions, generally pay-

ing no attention to planes of weakness. They are finer-grained than their parent sill, but show here and there a feldspar as much as two inches in length.

One of the most interesting parts of the contacts is that which belongs to the area marked "Lake Winnipiseogee gneiss" by the survey in the towns of Antrim and Hillsboro. It is exceptionally well exposed at intervals for a distance of five miles, and especially on the long ridge some two miles west of Antrim. The name thus given the rock with which the porphyritic granite here comes in contact is a decided misnomer. The new terrane consists of an ancient metamorphosed eruptive cutting the "Ferruginous" rocks in every way similar to the schists that extend from Bennington to Henniker. This complex is itself cut by the porphyritic granite.

The older eruptive rock is a typical coarse granitite containing a good deal of muscovite which is all secondary. The quartz is the common blue variety of New Hampshire crystallines. Both orthoclase and a basic plagioclase occur, but they are generally badly decomposed. It is a difficult rock to diagnose thoroughly on account of the vast amount of crushing which appears in the thin section. The quartz and feldspars are much granulated marginally, the unbroken cores showing the characteristic wavy extinction. The plagioclase lamellæ are often bent through large angles. Minute faulting is common in them, and throughout the slides the shreds of biotite are bent and twisted in a striking manner, while the extinction on the base of biotite plates is most irregular. In fact the condition of this rock is in marked contrast with that of the porphyritic granite close by. The granite is quite without any signs of serious disturbance; the granitite has endured the very severe mechanical strain of extensive mountain-building. Often the signs of developed schistosity in this once massive rock are easy to discern in the ledges, and these new structure planes strike a few degrees east of north, *i. e.*, they lie in the main parallel to the strike of the "Ferruginous" terrane.

Now, within the crushed granitite there is an extraordinary

display of inclusions, varying in size from small fragments to masses twenty feet square, all of which have evidently been derived from the older schists to which they are mineralogically and structurally similar. These horses are highly ferruginous, and weather with the same rusty appearance that characterizes the parent rock. So great is their number in some places that considerable stretches are veritable flow breccias. But it is rather the remarkable crumpling and other evidences of intense folding which attract one's attention to these outcrops. The sliverlike horses are very often bent into sigmoid flexures; sometimes one is seen to be completely doubled back on itself in a nearly closed fold. They are usually much jointed, and here and there actual movement along a fault plane may throw one part of the inclusion a foot or more out of its normal continuity. While there is not much difference mineralogically between these inclusions and the rock of the ferruginous terrane, yet there is some evidence of a metamorphic change due to the granitite. About one of them, some two feet long and a foot and a half broad, in particular, a two-inch zone filled with large biotites was developed. The biotite of the granitite itself is often segregated in large individuals. Many of the horses have been considerably melted up, and it is probably the absorption in this way of so much of the iron oxides that conditions the characteristic deep reddish brown color of the weathered granitite.

This terrane has but few affinities with the simple Lake Winnipiseogee mica-gneisses, where they occur in their normal fresh uncrushed habit. No evidence is yet forthcoming that the latter are eruptive. Not only do these multitudinous horses prove the eruptive origin for the granitite, but its actual contact with the ferruginous schists was found on Riley Mountain, and it tells the same story. The usual field criteria of the presence of horses, apophyses, and intrusive sheets are there exhibited. A rock zone of the foregoing description, averaging rather more than a quarter of a mile in width, runs southward five miles to the Antrim ridge above mentioned, always appearing between the porphyritic granite and the main body of schists.

At many places along its western margin the porphyritic granite cuts the granitite, but often passing into it by a zone of transition analogous to those described in the Winnipiseogee area. Thus we have added another to the crystalline terranes which have been profoundly affected by dynamic processes since their formation; they are in this respect to be contrasted with the younger relatively unaltered porphyritic granite, and lastly, they are of interest not only from their relation to the history of igneous activity in the state, but also from the light that they throw on the age and origin of the granite.

REGINALD ALDWORTH DALY.

(To be continued.)

THE MEASUREMENT OF FAULTS.

According to the definition given by Dana, "faults are displacements along fractures." Whenever the rocks of the earth's crust are subjected to strain, fractures take place in them as in any other body under similar conditions, and the different parts of the rock tend to move past one another along the fracture-planes, seeking to obtain relief from the strain and to accommodate themselves to new conditions. In this movement one part of the fractured rock-mass may move upon the other in any direction, up, down, sidewise or obliquely, according to the conditions, which are different in each instance. There is, so far as I know, no law governing the direction of movement in faults which is of any use in geological diagnosis. Naturally, when there is any preëxisting plane of weakness of the rock which is subjected to strain the movement takes place by preference along this plane; and, hence, in sedimentary beds, it is probable that movements along the stratification planes constitute the commonest variety of faults. Inasmuch, however, as the beds in disturbed districts lie in every conceivable position, the probability just stated does not give any clew to the average attitude of faults.

The movement in faults can be completely ascertained only by the aid of independent and accidental phenomena. In homogeneous rock-masses (leaving out of consideration fault scarps, fault gulches, and other topographic phenomena, and treating the faulted mass as a solid without boundaries), the amount of movement cannot be ascertained or even approximately estimated; although the *existence* of a fault can be determined by the records left on the slipping surface or surfaces in the shape of ground-up rock or fault-breccia, in polished and striated rock faces, and so on. It is certain, however, that the amount of friction as displayed by trituration and polishing is not neces-

sarily proportionate to the amount of movement, since faults with slight displacement are often accompanied by zones showing profound trituration, while others of far greater movement show to a much less degree the effects of friction. The friction in each case seems to depend upon the angle of the chief stress to the sliding plane, rather than on the amount of movement along this plane. In heterogeneous rocks the amount of movement of a fault can ordinarily be estimated with more or less accuracy, the degree of closeness depending upon the nature of difference in the composition of the rock-mass. In such heterogeneous rocks the amount and direction of a fault movement must be judged by any available phenomenon or phenomena. By far the commonest variations in rock-masses which are constant enough to be reliable as data are sedimentary beds, and therefore the commonest means of measuring a fault movement is the separation of the two parts of an originally continuous stratum. On this account it is easy to fall into the error of considering faults simply as dislocations of strata. In careful geological work, however, such as mining work must necessarily be, it is important to cultivate a more correct conception, and to regard sedimentary beds as phenomena accidentally associated with faulting, whose dislocation must be associated with all other available criteria, each one as valuable as the other, to determine the amount and direction of the total movement or displacement. Any fault, for example, in which the direction of movement is parallel with the plane of sedimentation will not cause any apparent displacement in a sedimentary bed; and this may be the case in faults having any conceivable attitude, since the sedimentary beds themselves may be folded so as to stand in any conceivable attitude with reference to any fixed plane, such as the earth's surface.

When the direction of movement in a fault lies at a slight angle to the plane of sedimentation, the apparent displacement of a stratum resulting from this fault will be only a slight part of the actual fault movement; and it is only when the direction of movement is perpendicular to the plane of sedimentation that

the separation of the parts of the faulted stratum is an accurate measurement of the movement. Theoretically speaking, the chances are infinitely against any such coincidence, and in actual practice it is rare that the movement may be even approximately estimated in this way. In mining geology it has been found that the most valuable criteria for measuring faults are, besides sedimentary beds, igneous bodies, such as dikes ; bodies of ore ; striæ on the fault plane, showing the direction of movement ; and the composition of the fault breccia, which may show, in some degree, the amount of movement. By taking several of these criteria together it is often possible to actually ascertain the movement of a fault.

It is sometimes possible to find out the amount and direction of movement immediately ; but more often it must be indirectly calculated, and to do this it is important to have clearly in mind the nature and value of some of the principal functions of a fault movement, and to have specific terms by which to designate them. The terms already in use are of a rather vague and general character, resulting from the usual conception of a fault as a dislocation of strata ; the four generally employed are *displacement*, *throw*, *heave*, and *offset*. The words *displacement* and *throw* are used interchangeably, and commonly refer to the separation of beds by a fault as seen in a vertical section. Each of these terms is used by some to indicate the distance along the fault plane between the broken ends of the bed as seen in the section, and sometimes the perpendicular distance between the parts of such beds, projected, if necessary. There is no agreement, however, which definitely assigns the terms to separate measurements, and, indeed, it is very common for a writer to use the terms interchangeably for one or the other function. *Heave* and *offset* are also used interchangeably, and are usually held to signify the perpendicular distance measured on a horizontal plane, such as the earth's surface, between portions, projected, if necessary, of a bed separated by a fault.

In mining work it is generally necessary to clearly differentiate the different functions of a fault movement, and I have

adopted the following terms descriptive of the most important of these; these terms include nothing very novel in the way of nomenclature, but are intended simply to affix definite names to definite things.

Dislocation and *displacement* are general terms, applicable to any part or the whole of a fault movement. Each of the functions defined below, and to which specific names are given, may be called simply a dislocation or displacement.

Total displacement is the distance which two points originally adjacent are separated by the fault movement; the line connecting these two points lies in the fault plane in all straight faults. It is occasionally possible to determine the total displacement directly by such criteria as the separation of the parts of an ore body, the intersection of a given dike with a given stratum when found on both sides of the fault, and in other ways; but ordinarily it can only be calculated or approximately estimated from some of its more easily measured functions.

The *lateral separation* is the perpendicular or shortest distance between the two parts of any continuous zonal body (such as a sedimentary bed), which has been separated by a fault, the distance being measured along the fault plane. The lateral separation may be measured in a vertical, horizontal, or oblique line, according to the attitude of the bodies between which it is measured, and in any fault it may vary from zero to the total displacement. In the case of dikes cutting sedimentary beds, of marked unconformity, of abrupt folds, and so on, it may be possible to measure two or more lateral separations in a single fault. In this case, and in a number of others which are possible, the total displacement may often be calculated from the lateral separation, since the latter is always the side of a right triangle of which the former is the hypotenuse.

The *perpendicular separation* is the perpendicular distance between corresponding planes in the two parts of any single body available as criterion (such as a sedimentary bed), when this body has been separated by a fault, the planes on each side of the fault being projected for the purpose of measuring, if neces-

sary. The perpendicular separation thus has a certain relation to the lateral separation; for it constitutes a side of a right triangle, the hypotenuse of which is the lateral separation, except in the possible case where the perpendicular and lateral separations coincide.

This mathematical relation makes it often possible to estimate the lateral separation from the perpendicular separation, and from the latter the total displacement. Of these three functions, the perpendicular separation is most easy of measurement, and its value may vary from zero to the full amount of lateral separation. The lateral separation is easier to ascertain than the total displacement, and its value may vary from zero to the total displacement.

The measurements which have been defined have no constant direction, since they refer to fault movements which are capable of infinite variation. In general geological work, however, it is often only possible to measure fault movements along certain arbitrary planes. The most valuable of these planes, are the earth's surface, which may be considered a horizontal plane, and vertical sections, into which available data are put, with the gaps in the chain of information often theoretically filled out. In such cases, where some dislocation is evident, but the information is so meager that it is not possible to know the fault so accurately as to estimate even approximately its total displacement or lateral or perpendicular separation, it is necessary to employ specific terms to designate the known or estimated dislocations, although the relations of these dislocations to the total displacement may be unknown. For this purpose the terms *offset*, *throw* and *vertical separation* may be used. The terms *throw* and *vertical separation* are applied to the dislocations of a fault as seen in a vertical section; the term *offset* to the dislocation as seen in a horizontal section, such as the earth's surface may be considered to be.

A *throw* may be defined as the distance between the two parts of any body available as a criterion (such as a sedimentary bed), when these parts have been separated by a fault, the dis-

tance being measured along the fault plane as shown in a vertical section.

The *vertical separation* is the perpendicular distance between the intersection of the two parts of any faulted body available as a criterion (such as a sedimentary bed), with the plane of a vertical section, the lines of intersection being projected if necessary for the purpose of measurement. In perpendicular faults the vertical separation is identical with the throw; in all others it is less than the throw, but sustains a certain relationship to it, being one side of a right triangle of which the throw is the hypotenuse. Thus the vertical separation may vary from zero to the full amount of the throw. The throw is always a part of the total displacement, although with no definite relationship to it, and varies from zero to the full total displacement.

The term *offset* may be used to designate the perpendicular distance between the intersections of corresponding plane in the two parts of any faulted body available as a criterion, such as a sedimentary bed, with a horizontal planes such as the earth's surface may be considered to be; the planes being projected for the purpose of measuring, if necessary. Like the throw, the heave or offset is a part of the total displacement, but has no definite relationship to it.

To sum up, there are six terms proposed to designate the different parts of a fault movement, each term applying to a measurement which varies in accuracy and proximity to the total displacement in proportion to the available amount of information. For general outline work where accurate data are not obtainable, the terms *throw* and *vertical separation*, referring to the measurements of a fault at its intersection with a vertical plane, and the term *offset*, indicating a measurement of a fault at its intersection with a horizontal plane, are adopted. The throw and offset are parts of the actual fault movement, but of unknown value, while the vertical displacement sustains a certain relationship to the throw. Where more complete data are obtainable, the terms *total displacement*, *lateral separation*, and *perpendicular separation* are adopted. The perpendicular separation sustains a certain rela-

tionship to the lateral separation, as the lateral separation does to the total displacement.

The terms which have been adopted above have purposely been made as few as is consistent with the plan of furnishing a scheme for complete fault-analysis. The number might be increased indefinitely; yet ordinarily this is undesirable, for most other fault measurements are simple mathematical functions of the terms above adopted, and can be easily reduced to one of these; and the great multiplication of terms leads to confusion in a study which is at best not too simple. In specific instances, however, it may be desirable to increase the number of terms, and to give separate names to other fault measurements.

J. EDWARD SPURR.

THE DRIFT AND GEOLOGIC TIME.

Assuming the correctness of the ice-sheet or glacier theory of the origin of the drift which, according to one supposed to be of high geological authority,[1] "has passed from the region of hypothesis to that of demonstration, and should form the basis of all reasoning on the subject," there are still many problems that are open to discussion and in regard to which writers widely vary in their opinions and statements. One of these is the lapse of time between the beginning and the end of the period, that portion of geologic time required to prepare for and lay down the drift deposits and to return to present climatic and physical conditions. Of late years there has been a tendency in some quarters to reduce the estimated length of this period. According to Prestwich[2] 25,000 to 35,000 years would suffice for the whole period of formation and retreat of the ice-sheet. Professor Wright endorses this estimate,[3] and Warren Upham[4] even abbreviates it a little, allowing only 20,000 or 30,000 years for the actual glacial period, and 6000 to 10,000 years for the since intervening time. Becker,[5] figuring on astronomical data, thinks that conditions favoring the glaciation of the territory covered by the drift may have existed within 40,000 years, and presumably gives that as the probable outside figure for their occurrence.

On the other hand, perhaps the larger number of glacialists have allowed in their estimates very much longer periods. To say nothing of Croll, Ramsay, Geikie, and earlier writers, we

[1] Geol. Mag., new ser., Decade IV, Vol. IV, 75, February 1897. (Review of Croll's Life and Work.")

[2] "Geology," p. 534, 1888.

[3] Man and the Glacial Period, p. 364, 1895.

[4] Bull. Am. Geol. Soc., V, 99, 1894.

[5] Am. Jour. Sci., 3d ser., XLVII, 95–113.

have, amongst recent writers, R. Bell,[1] who thinks the estimates of the above-mentioned authors *not* excessive. Chamberlin[2] estimates the lapse of time since the Kansan epoch to be equal to fifteen times the lapse since the last epoch, which would give a high figure for the whole period on any tenable estimate of this last factor, and to this is to be added an undetermined number of years for the pre-Aftonian (Albertan) stage. Penck, at the recent Toronto meeting of the British Association, is reported to have allowed at least 500,000 years for the glacial epoch, including all the interglacial stages, and very recently F. B. Taylor,[3] in an article on the moraines of recession of the latest (Wisconsin) ice-sheet, gives as his estimate of the time required for the retreat of this single ice invasion from the latitude of Cincinnati to the straits of Mackinac, a period of from 75,000 to 150,000 years. Adding to this an equal lapse of time for its advance, and we have an estimate of 150,000 to 300,000 years for the whole time occupied by this most recent member of the drift.

In addition to the actual periods of the ice occupancy of the territory we have to reckon in the interglacial epochs of which there is considerable evidence, and which must materially add to the length of Pleistocene time. I have not seen many estimates of the time required by these, the most noteworthy one being that of Professor McGee, of the time required for the deposition of the forest bed overlying the earlier Iowa till. Taking for his unit the period of written history, the very least figure he gives for this formation is about 112,000 years, and this is far exceeded by his estimate of its possible maximum duration. The thickness of some of these intercalated beds would naturally indicate a considerable period for their deposition, but McGee's estimate certainly seems an extreme one, and is the more noticeable when considered in connection with the relatively very short allowance of time he has given for the ice invasions themselves, even allowing, as we should, that he is

[1] Bull. Am. Geol. Soc., I, 295.

[2] Jour. Geol., IV, 875, 1896.

[3] Jour. Geol., V, 1897, July–August.

considering only the peripheral portion of the ice-sheet and not its greatest development. The length of the interglacial epoch must in any case enter as a very important element in our estimates of the total time required for the deposition of the drift, and the limited data from exposures are at best more suggestive than definite in the information they convey as to this point.

With these divergent views as to geologic time it would not appear as if the glacier theory afforded a very satisfactory basis for reasoning upon this particular phase of the subject. There certainly seem to be decided difficulties in utilizing the drift phenomena for the measurement of geologic time, each apparently possible solution of the difficulty seeming to present still more impossible problems. Some of the estimates made appear to be compromises, therefore, or alternatives, accepted only as better than something else. Thus Prestwich and Wright find it easier to limit the duration of the glacial period than to admit the possibility of man having existed 80,000 years on the earth, or that the fauna or flora of today could possibly be the same as that of 240,000 years ago. The elements of individual prepossession and mental idiosyncrasy enter largely into the consideration of scientific questions, and all the more into such as this where the chances of legitimate difference of opinion are so ample.

It is the object of this paper to call attention to the method of calculating geologic time by the transportation of erratics, a method that has up to the present time hardly received the attention it deserves in the literature of the subject. It is at first sight a little remarkable that this should be the case. That some at least of those who have alluded to it appear to have discredited its value is also remarkable, as any method that adds any degree of certainty to our estimates ought to be regarded as a boon to science. While, as I shall attempt to demonstrate, it has its value even with the rather indefinite notions we have hitherto had as to the flow of continental glaciers, recent researches by Chamberlin and others on the Greenland ice-sheet have added very much to its importance and applicability. We

have by it at the present time the data which enable us to form a definite minimum estimate of the time required for the deposition of the drift in North America, on the presumption that this was done through the agency of land-ice, or glaciers. If it is assumed that the drift was water laid, either altogether or to any considerable extent, altogether different elements enter into and affect the calculation, but that is not the assumption of the present paper.

It is perhaps conceivable that the climatic conditions during the formation of the ice-sheet were such that it was deposited by precipitation simultaneously over the greater part of the area it occupied. The névé, in other words, might have been almost coterminous with the glacier, only a narrow external rim being excluded. The evidence, however, of motion throughout at least the greater part of its extent is afforded by the erratics many of which have traveled 600 or 700 miles or even more from their original beds. A bit of jasper conglomerate found south of Cincinnati must clearly have traveled from the north shore of Lake Huron, and fragments of Archæan or eruptive rocks found abundantly along the southern limit of the drift in Illinois could have had no nearer source than northern Wisconsin 500 or 600 miles away, if indeed they have not a still more northern origin. A bowlder or pebble from the north shore of Lake Superior, if found in southern Illinois, would have traveled nearly or quite 800 miles, and while I am not sure that any such have been identified, their occurrence there is altogether within the bounds of probability. Such erratics, according to the glacier theory, must have been conveyed as subglacial or intraglacial detritus and must have progressed with the ice certainly at no greater rate than the ice itself and almost certainly at a much slower one. We have no certain evidence what the progress of the glacier was, but it could not have been a rapid one. In existing glaciers the most rapid rate of motion is about seventy-five feet a day, but this occurs only during one or two months in summer, and in two or three exceptional Greenland glaciers where the ice, so to speak, is under pressure down a favorably

inclined valley from the great Greenland ice-cap, the nearest analogue to the immense glaciers of the drift period with which we have at present any satisfactory acquaintance. These rapid flowing glaciers are exceptional in Greenland, where the general movement of the ice is unquestionably very slow. They can be compared to rapids at the outlet of a lake. The Greenland ice-cap far overtops the bordering mountains, and yet in only some seventeen places along the whole Danish Greenland coast are there free outflows to the sea. While we know less of the other portions of the coast the general character is the same; a rapid motion is exceptional and it is a reasonable certainty—to quote Taylor[1] whose paper contains the latest discussion on this ice motion—"that the average movement of that portion of the border of the Greenland ice-cap that rests upon the land is extremely small. Of that portion which ends in the sea only a small fraction has a high rate of motion, as is shown by the lack of activity in the discharge of icebergs. When it is considered that the land border is very much greater than the sea border, and that of the sea border a portion has a relatively slow movement, it will be evident that the average rate of movement of the great ice-sheet of Greenland cannot be high; and the average rate of this border is the nearest available analogue to the border movement of the still more extended periphery of the ancient American or Laurentide glacier."

In fact it is impossible, when we consider that the Greenland ice-cap only abuts on the sea along a small portion of its border in the form of glacial tongues, and that the average movement of these is so small, not to believe that towards its interior the ice movement must be almost imperceptible—almost if not absolute stagnation. The Antarctic ice-cap is very little known to us, but its movement must also be very slow, judging from the discharge of icebergs. All the icebergs of the North Atlantic come practically from a few Greenland glaciers, making up altogether only a minute fraction of the whole Greenland coast. In the Antarctic, on the other hand, we know of hundreds of

[1] JOUR. GEOL. Vol. V, 442, 1897,

miles of continuous ice cliffs ending directly in water hundreds of fathoms deep, and have reason to believe that this is only a fraction of what exists, and yet icebergs are sometimes almost unknown in the southern seas for years at a time. Again there will be years in which they are abundant and extraordinary in size, but at no time is their quantity comparable to what ought to exist were the discharge anything like a free one along the barrier.[1] It can be reasonably assumed, therefore, from what we know at present that the movement of the southern ice-cap is also extremely slow, notwithstanding the favoring conditions of direct discharge into deep water.

The great Laurentide glacier, extending over four million square miles of surface, can also be safely assumed to have had a very slow motion as a whole, fully as slow as that of the Greenland or southern ice-cap. In fact the question arises, and is not at first sight readily answerable, how it had any motion at all. Gravitation certainly had less play than in Greenland, for instead of an area nowhere more than three hundred miles from the ocean [1] we have one eighteen hundred or two thousand miles in

[1] "As has already been stated, there are years of very few or no icebergs, and then years when great numbers are reported. In the year 1832, the southern ocean was so covered with icebergs that a number of whaling vessels, bound round Cape Horn, encountering them, put back to Valparaiso to await a more favorable season, because it appeared too dangerous to undertake the voyage. Again in 1854 there was a great accumulation of icebergs, and now during the past few years, notably 1892 and 1893, there has been another notable output from the great berg factories of the Antarctic regions. During the intervals between these periods there have been very few bergs reported. What causes this occasional great accession of bergs? Some authorities offer as a probable explanation the breaking off of the ice margin by volcanic eruptions, and others that earthquakes cause numerous pieces of the glacier to become detached and set adrift as icebergs, and others that unusual heavy annual snowfall is favorable for increase in number of bergs. The rapidity of glacier movement seems usually to regulate the number of bergs cast off. If the ice at the bottom of the glacier moves so slow that the melting of the margin on coming in contact with the salt water equals the advance, then we would have no icebergs, except perhaps those breaking off from the upper part of the outer margin, and these would be comparatively small." W. T. Gray, M. S. U. S. Hydrographic Office, Pilot Chart, N. Pacific Ocean, Nov. 1896.

[1] Prof. Chamberlin finds no evidence that the ice-sheet of Greenland ever very greatly exceeded its present limits.

diameter and one in which no reasonably supposable elevation could give a uniform slope varying appreciably from the horizontal. An elevation at the center of radiation of ten thousand feet (which is much beyond the most favorable interpretation which any known data will bear) with an ice-cap of as much more, would only make a slope of under half a degree in eight hundred miles, and of considerably less in some directions to the outer limits of the ice. Some glacialists, however, are liberal in their allowances of earth movement to account for the flow of the glacier. Mr. Upham,[1] for example, thinks that the strong current needed to transport bowlders from the southeast shore of Hudson Bay one thousand miles southwestward to southern Minnesota, would require a slope of at least fifty feet or more per mile, apparently unmindful of the fact that such a slope for the given distance would require an elevation of the ice-cap to the height of 50,000 feet, where precipitation would, if it occurred at all, probably be so slight as to seriously embarrass the formation of any considerable ice-cap whatever. It is not probable, however, that there was any uniform slope over the glacial field, and whatever effect was produced by gravitation could not be such as would cause a rapid motion of the ice, "faster than the Swiss glaciers."[2] The other theories that have been invoked for the glacier motion, the effects of thawing and freezing, expansion under varying temperatures, etc., are none of them, we think, counted as sufficient to cause rapid movement in so large a mass, as a whole, even by their upholders, and such estimates as two to five feet per day are hardly based upon a due consideration of the probable or possible physical conditions. Dana's[3] estimate that "the rate of motion could hardly have exceeded a foot a day, and may have been in most parts no more than a foot a week" is much more likely to be near the truth. Ice, except under special conditions of pressure or *vis a tergo*, barely moves on a slope of one degree, and an average slope

[1] Greenland Ice Fields and Life in the North Atlantic, p. 304.

[2] WARREN UPHAM. Bull. Geol. Soc. Am., III, 401, 1892.

[3] Geology, 3d ed , p. 539.

of a quarter of a degree for a thousand miles would require an elevation at the point of origin of the flow of something approaching five miles. The probability, and we may say the certainty, is that the slope was not uniform and that over large distances the ice traveled over dead levels, and in parts even stagnated, the upper part flowing over the lower débris-laden portions. That the contained débris has a retarding influence on the flow of glaciers has been urged by O. P. Hay,[1] I. C. Russell,[2] and R. D. Salisbury,[3] and it appears that this may even cause absolute stagnation under some circumstances. Even detached erratics seem to progress more slowly than the body of the ice in certain instances; witness the well-known observation of Professor W. H. Niles[4] on the Aletsch glacier where ice moved so much more rapidly than a contained bowlder as to leave a free tunnel for a considerable distance on its lee side. Even lighter substances appear to be occasionally retarded in their progress as compared with the ice. Recognizable remains of buried travelers have been taken out of Alpine glaciers even hundreds of years after their loss.[5] It is impossible, therefore, to claim that these erratics could have traveled at the same rate as the surface of the glacier, and when we consider that they bear the marks of having been subjected to scouring in the ground moraine that has left their surfaces flattened and striated, the probability of such a rate of progression is certainly very much diminished.

Allowing a flow of two feet per day to the ice-sheet, which is undoubtedly far above the real rate of the ice movement, it would require 7200 years for Mr. Upham's bowlder to travel its thousand miles from Hudson Bay to southern Minnesota, and this without any delay from friction or attrition in the ground moraine, or stagnation in the lower strata of the ice. Taking, also, into account the fact that the northern erratics are found at all dis-

[1] Am. Jour. Sci. and Arts, 3d ser., XXXIV, 52, 1887.

[2] Jour. Geol., III, 823–883, 1895.

[3] *Ibid.*, Vol. IV, 769–810, 1896.

[4] Am. Jour. Sci., 3d ser., XVI, 367, 1878.

[5] Sir Henry Howorth. Geol. Mag. N. S., Decade IV, Vol. IV, 127.

tances from their point of origin and at all levels in the drift, it seems sufficiently clear that we cannot measure the duration of any single ice invasion by the period required for the transportation of a single erratic from its northern origin to its outer verge, even allowing for all the retardation in the ground moraine. Every one of the Archæan fragments so commonly seen along the southern borders or the drift must have required some four thousand years, even if we allow it to have advanced two feet a day, to reach its present position and probably a much longer period, for there is no good reason to suppose that the mass of the ice-sheet itself advanced at any such rate. We can also allow a somewhat more rapid transportation of débris near the margins by floods, subglacial drainage, etc., and yet find our time limit tending to be too small. The Alpine and Scandinavian glaciers, with their steep gradients affording full play to the action of gravity, move on an average only a few inches a day. How the continental glacier derived its movement, except at its elevated origin and near its periphery, is one of the questions that no one has yet satisfactorily answered, and the inevitable conclusion from the known facts is that while motion undoubtedly occurred it must have been extremely slow.

The formation of the ground moraine must have required a very prolonged period of time, involving as it did the grinding up and working over of the rocks and other material that together make up the till. It does not matter whether it is held that it was mainly deposited under the ice-sheet by stagnation of contained débris, as suggested by O. P. Hay,[1] or as a continuous terminal moraine as the glacier retreated, as was held by Newberry.[2] In either case a long time must have been required.

In what has been said I have tried to show that a great ice-sheet thousands of feet in thickness, extending over a third of a continent, expanding from its center in the direction of least resistance towards its periphery, having over the greater portion of its area a very slight slope, and probably none at all

[1] Loc. cit.

[2] Geol. Survey of Ohio, Vol. II, 29; III, 34.

in parts; hampered by inequalities of the underlying surface and by the detritus it shears off from these, must have had a very slow, though irresistible, progress; and that, accepting the existence of such an ice-sheet and taking account of this slow rate of progression, the contained erratics, whose origin can be identified by the situations in which they are found and the distances they have traveled, will afford a better means of making an approximate minimum estimate of the duration of the Pleistocene period than any other at our command. By this we can assure ourselves with almost absolute certainty that a single ice invasion could not have taken place carrying a single erratic from north of the lakes to the southern limit of the drift in less than four or five thousand years, and this without taking any account of the time required for the change of climate, the gradual gathering of the ice, its recession, the probable slower motion of the erratics than of the ice mass as a whole, or its retardation by friction, as evidenced by its facetted and striated surfaces. Taking all these into the reckoning, we ought, it would seem, to triple or quadruple the time; and if, instead of taking the highest estimates of glacier motion, we accept the more reasonable and probable ones, the period will be still more prolonged. It is difficult to see how, under these circumstances, a single ice invasion could have begun and run its course within the limits of less than thirty or forty thousand years; and if we accept Dana's estimate of the glacier flow at one foot a day for a maximum, and one foot a week as a possibility, we would have to carry our figures very much higher. We have, however, according to some of the highest authorities, Chamberlin, Leverett, and others, five separate ice invasions to account for, besides interglacial periods of possibly equal or greater duration; and this greatly magnifies the necessary estimate of time for the whole glacial period. One of these ice invasions appears to have transported bowlders one thousand miles, which, at the liberal rate of two feet per day, would require 7200 years, and the others, from the average extreme distance to which erratics were transported, will equal certainly 500 miles, which would require

3600 years, or, in the aggregate, 14,400 years. The total, therefore would be, in round numbers, about 22,000 years for the mere transportation of a single erratic in each invasion, and that at an improbable rate of speed and without any allowance whatever for the time occupied in the formation, culmination, or retreat of the glacier, or for interglacial periods. It is sufficiently evident from these figures that the ice-sheet theory of the till formation is utterly incompatible with such estimates as those of Prestwich and Wright, which give the whole glacial period a duration of only 20,000 to 40,000 years.

It has been matter of surprise to me that so little weight has been given by authorities to the arguments from the calculation of the transportation of erratics in the estimation of the duration of the glacial period. Most of them absolutely ignore, or at least fail to utilize it, and those who do allude to it at all, like Helland,[1] give it only the briefest and most casual mention. It appears to me to be the one method by which we can obtain, not the actual, but the utmost possible minimum of duration of such an ice-sheet as the generally accepted glacial theory demands.

Professor W. J. Crosby[2] has offered the suggestion that, as the great mass of the rock débris of the till is local and has never traveled far from its place of origin, the northern erratics were transported largely by water in the glacial lakes that formed along the borders of the ice-sheet. Inasmuch as these are found throughout the till at all levels, his suggestion amounts practically to an admission that the whole mass in which they are disseminated was thus deposited, which is altogether inconsistent with the general tenor of his argument, and is almost, if not quite, equivalent to giving up the land-ice theory of the deposition of the till.

It may be worth while here to notice one or two estimates or statements in regard to the duration of certain stages of the glacial period by prominent glacialists. The recent estimate of

[1] Zeitschr. der deutschen Geologischen Gesellsch. XXXI, p. 76, 1879.

[2] Am. Geologist, XVII, 1896, p. 234.

F. B. Taylor of from 75,000 to 150,000 years for the recession of the Wisconsin ice-sheet from Cincinnati to Mackinac has been already alluded to in the early part of this paper. As against this apparently large, but possibly not too large estimate (that is, admitting the land-ice formation of the Wisconsin drift), it is interesting to quote Wright and Upham's[1] dictum that "the late divisions of the glacial period were far shorter than its Kansan, Aftonian and Iowan stages," and the estimate of Chamberlin[2] that makes the ratio of time to the present from the earliest Wisconsin and from the Kansan stages as 2½ and 15 respectively, leaving an undetermined figure for the still earlier portion of the glacial period. That would make, according to Taylor's figuring of 150,000 to 300,000 years for the Wisconsin invasion and retreat, a period of somewhere between 900,000 and 1,800,000 years back to the beginning of the Kansan drift. These figures are, it is true, rather staggering, but it is not absolutely necessary to accept the two estimates and combine them. There may be other ways of reckoning the duration of the separate stages of the drift. Certain it is at least that neither of these authors is to be held responsible for the estimates of the other, or the combination of the two.

In conclusion, the reasoning of this article may be summarized as follows:

The estimates of the duration of the glacial period by prominent geologists vary almost as widely as possible. It is probably useless to attempt to obtain any approximate estimate of its maximum duration, but we have in the transportation of erratics a simple method by which an ultimate minimum of the time occupied may be obtained. Accepting the land-ice hypothesis of the deposition of the till, we must from all analogies, and all our knowledge of glaciers and ice-caps, admit that the motion of the ice-sheet was slow, and that it probably did not exceed a few inches a day; indeed, apart from the evidence of the till and its contained erratics, it is hard to find any grounds for belief in its motion over large proportions of the occupied territory. Erratics

[1] Loc. cit., p. 360.

[2] Loc. cit.

that are known to have been transported distances of from 500 to 1000 miles could not have traveled faster than the main body of the ice, and must, as we know from the evidences they bear of retardation and friction, have traveled much more slowly. Even allowing the extravagant estimate of two feet *per diem* for the ice movement throughout (and the recent investigations of Chamberlin and others on the Greenland ice-cap have demonstrated that this is an improbability) we can demonstrate that a single invasion competent for the transportation of a single erratic from its northern source to the southern limits of the drift would have required a period of from 15,000 to 20,000 years.[1] If we admit, as is more reasonable, that the average ice motion was much less than this,—probably not over a very few inches *per diem*, we will have to more than quadruple this estimate. Taking into account, however, the inevitable conclusion that the duration of a single ice invasion was not limited to the conveyance of a single erratic or simultaneous group of erratics, and that there were, in all probability, several of these invasions with intermediate periods of sufficient length to allow the development of extensive forests and the accumulation of heavy deposits of vegetable mold, indicating a lapse of probably many thousand years, we are compelled to multiply the above figures by an indefinite multiplier. The outcome in any case is that the brief duration allowed for the glacial period by some recent authorities is absolutely incompatible with the evidence of erratics, according to the land ice or glacier theory of the deposition of the drift.

[1] I have not in my argument taken account of the slowness of advance of the ice border which must also be considered in calculating the total. Opposed to each year's advance there must have been a summer's melting, and judging from the evidence of the Greenland ice-cap, this latter element must have been of considerable importance. The Greenland ice-sheet hardly gains at all upon the unoccupied land even in North Greenland, the ice surplus all escaping by the few glacial outlets which are much less active than those in South Greenland. In the case of the Laurentide glacier trenching upon a fairly temperate region with a long summer, the estival melting must have been quite marked. The additional transportation by flood torrents, etc., can be estimated by the extent of the till deposits as compared with glacial striæ, which even in southern Illinois are reported as found on the underlying rocks nearly to the southern margin of the drift.

I have not attempted in this article to exhaustively discuss the evidence of the slow motion of the ice in the Laurentide glacier. Much more could have been said on that point, but any-one who has followed the recently published studies of glacial phenomena in Greenland by Chamberlin, Salisbury, and others, will be able to supply most of the deficiencies in my argument. The present paper is simply the statement of views that were suggested by a consideration of some aspects of the glacial theory as an amateur geologist.

I wish to also acknowledge here my indebtedness to Professor T. C. Chamberlin for valuable suggestions on certain points here discussed.

H. M. BANNISTER, M.D.

CHICAGO.

ON THE PRESENCE OF PROBLEMATIC FOSSIL MEDUSÆ IN THE NIAGARA LIMESTONE OF NORTHERN ILLINOIS.[1]

For more than a year past my attention has been directed to some peculiar fossils from the dolomitic Niagara limestone of northern Illinois, in the collections of Walker Museum at the University of Chicago and of the Chicago Academy of Science. The exact horizon and location from which the specimens were obtained have in no case been recorded, but the general locality for them all is Joliet, Ill. Additional specimens have recently been secured from the excavations of the Chicago drainage canal, by Mr. L. H. Hyde, of Joliet, and these have been kindly loaned for study.

The complete specimens of this peculiar fossil are disk-like impressions, subcircular in general outline, with the periphery lobed, and with the surface radiately corrugated or smooth. In the center of the disk is a funnel-shaped depression and from the center of this depression a stemlike process rises to about the general level of the surface of the disk. The disk is divided by four ridges, radiating at right angles from the center, into four quadrants. The entire disk is rarely preserved intact, the larger number of specimens being the separate triangular quadrants. Several species are represented in the collection which differ in

[1] Just as this paper is going to press additional material from the collection of Mr. E. E. Teller, of Milwaukee, Wis., has come to the writer, which throws a very different light upon the nature of *Cryptodiscus*. One of the specimens in this collection shows a complete disk of *Cryptodiscus* situated at the summit of a tube composed of plates which are arranged essentially as the plates in the anal tube of *Callicrinus*. The evidence of these specimens seems to establish the fact that *Cryptodiscus* is a remarkable disk-like expansion of the four plates forming the terminal ring of the anal tube of some crinoid, probably *Callicrinus*. Additional evidence for the correlation of *Cryptodiscus* with *Callicrinus* is found in the fact that the genus *Callicrinus* occurs at every locality where Cryptodiscus has been observed. The specimens in Mr. Teller's collection will be illustrated and more fully described at another time.

the lobing of the periphery and in the ornamentation of the disk. As in the case of most of the fossils in this formation, the actual substance has been dissolved out leaving a mold in the rock, and the specimens which have been collected are generally but one side of a thin disklike cavity. None of the specimens have been actually observed *in situ*, but it is believed that the specimens usually collected, viz., those with the central depression and elevation, are the lower sides of such cavities. The upper sides are not so striking in appearance, and have usually not been preserved by collectors. A few have been observed, however, and they differ from the lower sides in being nearly plane over the central part, the funnel-shaped central depression with the central stemlike process being absent. Figure *A* represents diagramatically a cross-section of the fossil, cutting the disk diametrically.

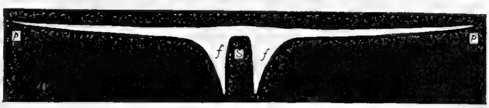


FIG. A. *pp* points upon the periphery of the disk. *f* the funnel-shaped depression in the center of the lower side. *s* the stemlike elevation in the center of the funnel-shaped depression.

In examining the literature, two references have been found to fossils similar to those under consideration. The first of these is in the Twentieth Report of the Regents of the New York State Cabinet of Natural History, where Dr. James Hall, on Plate XI, Fig. 18, gives an illustration of a similar fossil, also from the Niagara limestone. No description of the specimen is published further than the note in the explanations of the plate, which is as follows: "The calyx of a Crinoidean? of a new and peculiar type, for which I suggest the name Cryptodiscus." No locality for the specimen is given, but the species in the accompanying paper are all from southeastern Wisconsin or northern Illinois.

At a more recent date, in the Eighteenth Report on the Geol-

ogy and Natural History of Indiana, Mr. S. A. Miller has illustrated a single quadrant of a similar fossil from the Niagara limestone at St. Paul, Ind. A short description is published, but no name is given to it. Mr. Miller states in his description that he has seen a similar fossil from the Niagara limestone near Chicago, circular in outline, and made up of four such segments as he illustrates from St. Paul. The fossil he had in mind is doubtless one of those illustrated in the present paper.

Since the fossil to which Hall gave the name *Cryptodiscus* is without doubt a form similar to those under discussion, his name will be used in their description, although it has never been properly published.

No satisfactory explanation of the nature of *Cryptodiscus* has been given by either Hall or Miller. Hall's statement with a query, that it is the calyx of a crinoidean can hardly be correct as the quadrangular symmetry is unlike that of the corresponding part of any crinoid. Miller states that some collectors have considered the fossil to be the operculum of a coral, but he himself does not seem to regard this interpretation of it as the correct one. The genus *Goniophyllum* is the only coral possessing an operculum of four triangular plates, but *Cryptodiscus*, from the configuration of the disk, need not be compared with the operculum of *Goniophyllum*.

After a careful consideration I am led to believe that these peculiar fossils may be the remains of medusæ. Though the modern jellyfish are often of large size, they are singularly unfitted for preservation as fossils because of the entire absence of hard parts. Under favorable conditions, however, impressions of these organisms have been preserved which admit of systematic determination. Such impressions have been described from the Upper Jurassic and the Upper Cretaceous in Europe. Of a more questionable nature are the Cambrian fossils from Sweden and America which have been referred to the Medusæ by Nathorst and Walcott.

Although *Cryptodiscus* has in general the symmetry of the medusæ, the idea of its being the mere impression of such a

creature is abandoned for two reasons: First, the specimens are not mere impressions in the rock, but are cavities with an upper and a lower side, from which the actual solid substance of some fossil has been dissolved. In the second place there is no reason why the mere impression in the mud of the umbrella of medusæ, should generally break into regular quadrants and be preserved as such. If we consider, however, that the specimens of *Cryptodiscus* are the casts of the gastric cavities of medusæ. both of these difficulties are eliminated. The gastric cavities of some living medusæ are divided by thin partitions into four pouches.[1] If such a gastric cavity were filled with a fine sediment, and if after the decomposition of the soft parts of the creature, this cast should become fossilized, it is easy to imagine that the four lobes of the cast might often become partially or wholly separated or destroyed during the process. The one serious objection to this theory is that probably the material originally filling the cavity of the medusa would be so nearly identical with that in which the cast was buried, that it would not be leached out, as would the shell of a brachiopod, for instance, which was of a different character from the matrix in which it was buried.

DESCRIPTION OF SPECIES.

In reading these descriptions and examining the illustrations, it should be kept in mind that they have all been drawn from the impressions in the limestone and are consequently the reverse of what the actual fossil would be. That is, what is described as a groove in these impressions would be a ridge in the actual fossil.

Cryptodiscus corrugatus n. sp. Figs. 1–2.

Disk 7 to 10^{cm} in diameter, finely and deeply lobed on the periphery. Funnel-shaped depression in the center 10 to 15^{mm} in diameter on the plane of the disk, narrowing below to the base of the central stemlike process which is from 3 to 5^{mm} across and rises 6 to 8^{mm} to the general plane of the disk. Sur-

[1] See figure of a *Calycozoon* (*Lucernaria*), CLAUS and SEDGWICK, Text-Book of Zoölogy, Vol. I, p. 257, Fig. 197.

face of the disk ornamented with from 18 to 20 radiating corrugations on each quadrant, which extend about two-thirds of the distance from the periphery to the center. Each groove upon the corrugated surface extends to the tip of one of the narrow lobes of the periphery. Central portion of the disk within the proximal ends of the corrugations, with the exception of the central depression, plane. The whole surface of the disk, in well-preserved specimens, minutely pitted. The four ridges which divide the disk into lobes start from four angles upon the central stemlike process. These ridges upon the more weathered specimens become nearly or quite obsolete distally. The lobed periphery of the disk is rarely perfectly preserved, and in only the best-preserved specimens can the minutely pitted surface be observed.

The specimens figured are from the collection of Mr. L. H. Hyde; beside these the species is represented in the collections of Walker Museum and of the Chicago Academy of Science. It is the commonest species of the genus which has been observed, and to it may probably be referred the specimen figured by Miller from St. Paul, Ind.

Cryptodiscus hydei n. sp. Figs. 3–4.

Disk 5 to 8^{cm} in diameter, deeply lobed between the quadrants giving the entire specimens much the form a of Maltese cross. Distal margins of the lobes in no case perfectly preserved. Funnel-shaped depression in the center 10 to 12^{mm} in diameter on the plane of the disk, narrowing to the base of the central stemlike process which is 5 to 6^{mm} in diameter, rounded over the top, and rising from 5 to 7^{mm}, a little above the general plane of the disk. Surface of the disk smooth, sometimes with shallow, ill-defined radial depressions extending from the center along the lateral margins of each lobe to the distal angles. In one specimen a shallow, ill-defined radiating depression is seen extending from near the center of the distal margin towards the proximal angle. The four ridges which divide the disk into quadrants, start from four angles upon the central stemlike process and are prominent to the bottoms of the lobes of the periphery.

The specimens figured are from the collection of Mr. L. H. Hyde.

Cryptodiscus digitatus n. sp. Figs. 6–7. 5?

Only the detached quadrants of this species have been observed. Each quadrant is deeply divided into three primary lobes, the two lateral lobes being again divided in a manner not clearly shown in the specimens. Surface covered with fine pits which are coarser towards the proximal angles. Central depression narrow and deep.

In one specimen, Fig. 5, which may belong to a distinct species, the central lobe of the quadrant is deeply bifurcate, and the lateral lobes are more deeply and more divergently divided than in the type. This specimen is also of interest in showing two quadrants somewhat separated, but still holding their relative position.

The specimens figured are from the collection of Mr. L. H. Hyde.

Cryptodiscus bilobus n. sp. Fig. 8.

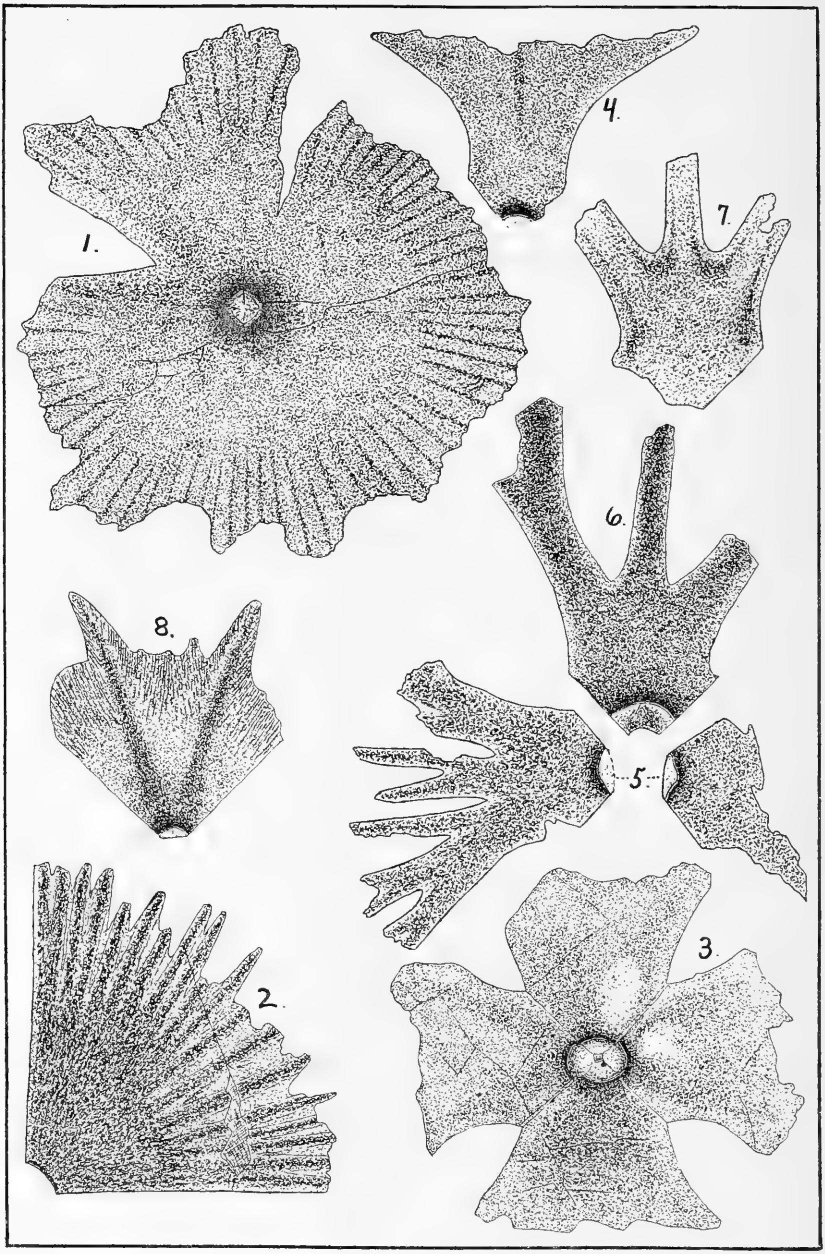
A single quadrant of this species has been observed, but that one is nearly perfect. The distal margin is divergently bilobed, with each lobe marked by a well defined, rounded, radiating furrow which extends nearly to the proximal angle, dividing the plane of the quadrant into three subequal triangular areas. Each of these areas is ornamented with fine striæ which diverge from the margins of the two radiating furrows. The central depression of the disk narrow and deep.

The type specimen is in the collection of Walker Museum.

EXPLANATION OF PLATE.

FIGS. 1–2. *Cryptodiscus corrugatus.*
- 1. A complete specimen with the periphery imperfect.
- 2. A single quadrant showing some of the narrow lobes of the periphery.

FIGS. 3–4. *Cryptodiscus hydri.*
- 3. A complete specimen with the periphery imperfect.
- 4. A single detached quadrant.


1.
2.
3.
4.
5
6.
7.
8.

FIGS. 5–7. *Cryptodiscus digitatus.*

5. Two quadrants detached but still holding their relative position. Possibly a distinct species.
6. The lower side of the type specimen.
7. The upper side of the type specimen.

FIG. 8. *Cryptodiscus bilobus.*

The type specimen.

STUART WELLER.

WALKER MUSEUM,
University of Chicago.

EDITORIAL.

THE seventh session of the International Congress of Geologists was, and undoubtedly will always remain, the most remarkable in the history of this organization. In conception and in execution its plans far exceeded those of any session that preceded it, and were much greater than may be expected for any that may follow. Governmental, industrial and social forces conspired to secure the success of the programme prepared by the Russian geologists. A most powerful government not only lent its hearty sympathy but furnished material assistance and coöperation. The Emperor and Empress received a delegation from all the countries represented at the congress, and all members in attendance were given a luncheon in the summer palace. The Grand Duke Constantine Constantinovitch and the Princess d'Oldenbourg and the Minister of Agriculture and Domains opened the session and welcomed the members to St. Petersbourg. The Grand Duke Constantine and the Grand Duchess Elisabeth Mavrikievna entertained a large number of the geologists at their palace. The mayor of St. Petersbourg invited all the members to a reception in the city hall. These tokens of good will and approval could not have been stronger; their genuineness was proved by the material benefits enjoyed by all who took part in the congress and the excursions. First-class passes were furnished over all the railroads of European Russia and Finland, good for three months, and entitling one to the use of sleeping cars. Many official courtesies were also extended which often amounted to complete freedom from customs and police surveillance, and greatly simplified traveling through various governmental provinces into remote parts of the empire. Industrial enterprises, in any way indebted to geological science, exhibited

the same energy in advancing the interests of the visiting geologists that characterizes their development of the natural resources of the country making it possible to inspect mines and study artificial exposures of great interest. The magnitude of their hospitality also will long be remembered. It was prompted by a generosity that seemed common to all classes of people throughout the empire, as was shown upon one occasion by the presentation of bread and salt by the miners of Coloubovka in token of the humble hospitality they would be glad to show us in their houses if we could have visited them. The same hearty welcome was met with in the cities and on the farms of Finland, among the miners in the Urals, and in the town, or camp, or monastery in Transcaucasia — everywhere the same generous spirit and the same expressions of good will.

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THE brilliant success of the seventh session reflects great credit on Russian geologists. To them are due both the conception and execution of the programme. The labor required for the preparation of maps and guides and for the arrangement for the meeting and the excursions can hardly be realized by anyone who has not been engaged in similar undertakings. The general secretary, Professor Tschernyschew, devoted two years to the preliminary work, and others, no doubt, had a very considerable share in it. The management of the excursions was admirable, when it is remembered what difficulties of transportation and limitations of accommodation had to be overcome and when the number of participants is taken into account. The gratitude of all the excursionists is due to the leaders of the several expeditions for the manner in which everything within their control was conducted. Their labors and good intentions were fully appreciated, except by those unfortunates whose first impulse on all such occasions is to criticise and complain, and whose subsequent effort is to find excuse for having done so. When it is remembered that in addition to their responsibility for the details of the excursion, the leaders have also to expound the geology and undergo a cross fire of questions and scientific

criticism, and not infrequently to have judgment hurriedly passed against them on insufficient evidence, the degree of indebtedness to those who undertake such responsibilities is even greater than at first appears.

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THE actual meetings of the congress were reduced to a minimum. Of the eight days set apart for the session in St. Petersbourg, four only were occupied by the reading of papers and by discussion; two were given to the opening and closing ceremonies, and two were taken for excursions. The wisdom of this allotment is open to criticism. But it was evident at the time that the most interesting feature of the session for the general member was the social intercourse between members, proving that the individuality of those present was of more immediate interest than the papers read. The audience room unfortunately was not well adapted to the purpose, owing to its large size and the interruptions by members passing through it. It was apparent to many that there would be a distinct gain if in future sessions there should be meetings by sections for those interested in specialized branches of geology, in connection with general meetings, in which all might be interested. It would permit the specialist to present more technical papers, and would allow of more time for their discussion without encroaching upon the time of others. Topics so diverse as palæontology and petrology could be treated at the same time without conflict, and with mutual advantage. The consciousness that a paper would be too technical for a general audience, and that it should be made as short as possible often deters one from devoting the necessary time to its preparation. But with the possibilities of an audience such as might be commanded at an international congress, and with time enough at one's disposal, there could be no stronger incentive for the presentation of one's best possible production. It is to be hoped that the French geologists will inaugurate this practice at the session in Paris in 1900.

The nature of the scientific proceedings of the session will be noted in another issue of the JOURNAL. J. P. I.

It is pleasant to announce that our colleague of the Journal staff, Dr. Hans Reusch, has been engaged to give two courses of lectures at Harvard University during the current year. In the first half of the year he will treat of vulcanism, volcanoes, eruptive rocks, earthquakes and other movements of the Earth's crust. In the second half he will describe the geology of northern Europe and its relations to general geology. He will give a weekly seminar to advanced students and will take part in their field and laboratory work, his special subjects being the geology of the seashore and the geology of special districts in Europe. These lectures are given on the Sturgess-Hooper foundation recently occupied by Professor J. D. Whitney, but vacant since his death. C.

Reviews.

The Unpublished Papers of the Geological Survey of Brazil. (*Frabalhos restantes ineditos da Commissão Geologica do Brazil.*) Boletim do Musen Paraense, Vol. II, No. 2. Oct. 1897, pp. 155–204.

At the suggestion of Professor O. A. Derby, now chief of the State Geological Survey of São Paulo, the Pará Natural History Museum (*Museu Paraense*) has undertaken to publish the unpublished papers of the defunct Geological Survey of Brazil relating to the geology and physical geography of the lower Amazon. The October number of the *Boletim* contains the first installment of these papers. The parts thus published consist of an "Introduction," "The Breves Region," and "The Rio Tocantins" by Ch. Fred. Hartt, and of "The Island of Marajo" and a "Reconnaissance of the Rio Mãecurú" by O. A. Derby. These are to be followed later by other chapters on "Rio Trombetas" by Derby, on "Paracary" by Herbert H. Smith, and on the "Tajury," "Paranaquara," "Serra da Maxira," and "Monte Alegre and Ereré" by Hartt.

These papers represent work done by the extinct Commissão Geologia do Brazil from 1875 to 1878, and it might be supposed that it is now too late to publish them, especially as the Museu Paraense has lately begun active work in the same region. But it should be remembered that the State of Pará, occupying the whole of the Lower Amazon, covers an area of 443,900 square miles—nearly twice that of the state of Texas—and that the difficulties of exploration in the dense and trackless forests that cover that sparsely inhabited region are almost or quite beyond the comprehension of those who have not encountered them.

As Hartt well says, when he entered the Amazon valley for the first time in 1870, it was, geologically, a *terra incognita*. Since that time and as the result of the tireless efforts of Hartt and Derby a vast amount of important information has been gathered and published

upon the geology of the Amazon valley. Among these contributions are Hartt's and Rathbun's papers on the Devonian fossils of Pará, Derby's papers on the Carboniferous and on the Physical Geography of the Lower Amazon, and Clarke's report on the Ereré tribolites, besides a number of papers of minor importance, but all of them of value.

Director Goeldi deserves great credit for bringing out at last the work of the men who have done so much and such important pioneer work for geology in Brazil.

The Devonian fauna of the Red Maecurú. By DR. F. KATZER.

The same number of the *Boletim* contains an interesting paper by Dr. Friederich Katzer on "The Devonian fauna of the Rio Mãecurú, and its relations to the faunas of the other Devonian terranes of the globe." His studies are based upon the materials gathered by Hartt and Derby and some later collections made in 1896. The conclusion is reached that the Rio Mãecurú fauna resembles more closely that of the middle Devonian of North America than it does the lower Devonian with which it has hitherto been correlated. One of the beds he correlates more exactly with the Hamilton of the New York section. In comparing the fauna with the Devonian of Europe he says it should be compared to the upper part of the lower Devonian. "But as there can be no doubt that the Rio Mãecurú fauna corresponds to that of the Hamilton of North America, which is now considered to belong to the middle Devonian we are obliged to assume *a non-simultaneous development of certain forms in the American and European provinces of the Devonian sea, or a migration of these forms from the latter to the former provinces.* Thus the spirifers with long wings show their principal development in the Rhenish Lower Devonian, but in North America and on the Rio Mãecurú only in the middle Devonian. *Fropidoleptus carinatus* Conrad is found on the Rhine in the lower Coblenz beds, while in America, including the Rio Mãecurú territory, it occurs only in the middle Devonian. The same is true of corals of the genus *Pleurodictyum* which, in Europe, are found predominating in the lower Devonian and in America in the middle Devonian.

"All this shows that these groups of animals, probably on account of progressive alterations, especially of depth, in the sea of the first

Devonian epoch, migrated from Central Europe to America where they are now presented in the middle Devonian."

Dr. Katzer's study of these Brazilian fossils is especially interesting in connection with the work of Dr. Henry S. Williams on the fauna of the Cuboides Zone. (Bull. G. S. A. I. 481–500.)

JOHN C. BRANNER.

Report of the United States Deep Waterways Commission. By the Commissioners JAMES B. ANGELL, JOHN F. RUSSELL, LYMAN E. COOLEY. Washington, 1897.

The Deep Waterways Commission was appointed by the President in response to a joint resolution of Congress, introduced in February 1895, to make inquiry and report after conference with such similar Commissioners as might be appointed on behalf of Great Britain or the Dominion of Canada, concerning the feasibility of the construction of canals which will enable vessels engaged in ocean commerce to pass into the Great Lakes. The United States Commissioners and also those appointed by the Canadian government have devoted a year or more to the investigation and have prosecuted their inquiries with such thoroughness that their report contains much of value to geologists and hydrographers as well as the commercial world. It embraces 263 pages of descriptive and statistical matter and an elaborate series of maps, diagrams and profile sections.

Of interest to geologists and hydrographers are the tables and diagrams exhibiting the fluctuations in the levels of the Great Lakes and their outlets for each month from 1860 to 1895; a report and diagrams setting forth the effects of gales on Lake Erie; and an accurate map of the basin of the Great Lakes. The length of the ice season is treated with great fullness, there being 176 specific tables and five diagrams, covering not only the basin of the Great Lakes but much surrounding territory. The profiles setting forth the variations in depth of the several lakes with their connecting channels and of the St. Lawrence and Hudson rivers, give a clearer impression than can be obtained from charts. The great inequalities in depth found in the lower portions of the Hudson and St. Lawrence rivers are brought out with especial clearness, and they will stimulate inquiry into the history or mode of development of such abnormal stream beds.

The leading deductions from the work of the commission are as follows: First, that it is entirely feasible to construct canals between the several Great Lakes and the seaboard which will be adequate to any scale of navigation that may be desired; second, the most eligible route from the heads of Lakes Michigan and Superior is through the several Great Lakes and their intermediate channels, together with a proposed ship canal from Tonewanda to Olcott in Lake Ontario, from which the Canadian seaboard may be reached by way of the St. Lawrence River, and the American seaboard may be reached by way of the St. Lawrence River, Lake Champlain, and the Hudson River, or by way of the Oswego-Oneida-Mohawk Valley, and the Hudson River. The direct line through Georgian Bay, Lake Nipissing, Mattawa, and Ottawa rivers, although presenting no great engineering difficulties, is not considered an available alternative to the route by way of Lake Erie, since the work of construction is much more serious, the water supply limited, the ice season longer, and the amount of traffic along the line much smaller. Until comprehensive surveys have been made it will be impossible to say how far lockage and restricted channels will offset the apparent saving in distance. F. L.

The Former Extension of the Appalachians across Mississippi, Louisiana and Texas. By PROFESSOR J. C. BRANNER. From the *American Journal of Science*, Vol. IV, November 1897.

The paper is a brief and compact statement of the ground upon which the author concludes that the Appalachian Mountains formerly had the extension indicated by the title. That the mountains disappeared by subsidence over the area named is evidenced by the following: (1) the reversal of the drainage of both the Arkansas and the Texas Carboniferous areas; (2) the truncation of the eastern part of the Ouachita uplift by Cretaceous and Tertiary sediments; (3) the general slope of the Ouachita uplift is toward the east; (4) the general direction of the drainage of the Ouachita uplift is toward the southeast, which is the direction of the principal axis of disturbance; (5) the faults and folds across the eastern end of the Boston Mountains are approximately parallel to the Cretaceous and Tertiary margin; (6) the great fault near the Tertiary border of Texas and the still greater faults in Alabama, with the downthrow (which is great) on the embayment side of

the Appalachian axis; (7) the eruptive rocks and hot springs accompanying the faults and Tertiary border in Texas and Arkansas; (8) the great thickness (5000 to 10,000 feet) of the Cretaceous and post-Cretaceous sediments in the depressed area.

Among other important things, the author concludes that the Ouachita uplift is the structural equivalent of the Cincinnati-Nashville arch; that the Coal Measure drainage of the Illinois-Indiana-Kentucky area was into the Carboniferous mediterranean sea through the Arkansas valley; and that the drainage of the Arkansas and Texas Carboniferous areas was reversed about the close of Jurassic times, when the orographic movements to the east submerged the Appalachians in Mississipi, Louisiana and Texas.

The Palæozoic sediments on the south side of the Ouachita uplift are coarser than on the north side, indicating that they came from the the south. The same change of sediments is seen in the Silurian novaculites of the Ouachita uplift. It is on this ground that the Ouachita uplift is made the equivalent of the Cincinnati arch.

A. H. PURDUE.

ARKANSAS STATE UNIVERSITY.

Maryland Geological Survey, Vol. I. WM. BULLOCK CLARK, State Geologist. The Johns Hopkins Press, Baltimore, Md.

Following the good example set by some of the recent state geological surveys, the survey of Maryland presents in its first published volume a summary of the geological work which has already been done within the state. This ground is covered in Parts II, III and IV of the present volume, each of which treats of the subject from a different point of view. The first gives a history of the various organizations which have carried on geological work within the state, and references to the work of individuals not immediately connected with organizations. The next presents a summary of existing knowledge concerning the geology of the state, unencumbered by references to the men who did the work, the dates at which their results became known, and the publications where they were set forth, references which, if present, would seriously interrupt the continuity of the sketch. In this sketch are incorporated some of the results of the reconnaissance work of Dr. Clark and his assistants since the organiza-

tion of the present survey. The third part of the report referred to above (by Dr. E. B. Mathews), is a careful bibliography of the publications, both textual and cartographic, touching the geology and natural resources of the state. These chapters, which constitute the strictly geological part of the volume, are prefaced by a chapter which sets forth the plans and purposes of the survey — a chapter well worth the perusal of those who are charged with the organization or execution of such surveys.

Part V is a report by Dr. L. A. Bauer on the magnetic work in Maryland, and includes a sketch of the history and objects of magnetic surveys. Dr. Bauer has determined the magnetic elements at a number of points, and has brought together all data which are now known concerning this interesting subject, so far as applied to the state.

The volume is illustrated by seventeen well-executed plates and maps, among which are a geological map of the state as now understood, an isogonic map, and a map showing lines of equal magnetic inclination and the preliminary lines of equal magnetic force (for January 1897).

The volume is to be commended not only for its contents, but for the excellence of its typographic work. In this respect it is in pleasant contrast with the cheap volumes sometimes issued by similar organizations.

R. D. S.

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THE

JOURNAL OF GEOLOGY

NOVEMBER–DECEMBER, 1897

THE GEOLOGIC RELATIONS OF THE MARTINEZ GROUP OF CALIFORNIA AT THE TYPICAL LOCALITY.

THE term "Martinez Group" was first used by W. M. Gabb in his classification of the Cretaceous of California,[1] the group of strata provisionally so designated being considered by him as standing between the Chico of his Cretaceous A and his Tejon or Cretaceous B. The Martinez was said to be of small geographical extent and to bear such a relation to the Chico that future investigation might show it to be a part of that group. About sixty species were listed by Gabb from the group, most of them having been collected near the town of Martinez, in Contra Costa county.

For a number of years after the publication of the second volume of Gabb's work on the palæontology of California, the Martinez group was scarcely mentioned in geological literature, probably because, as described by him, it was not well understood. However as the Cretaceous B or Tejon came to be generally considered as Eocene the importance of the group, as a possible connecting link between the Chico-Cretaceous and the Tejon-Eocene, became evident.

[1] See Rep. Geol. Surv. of Cal. Palæontology, Vol. II, p. 13 of Preface. Gabb divided his Californian Cretaceous into a lower division, A, including the Shasta, Chico, and Martinez (?), and an upper division, B, or the Tejon. His Cretaceous B is now generally regarded as Eocene.

In a recent publication[1] by Mr. T. W. Stanton the fauna and stratigraphy of a number of the most important of Gabb's Martinez localities have been clearly discussed and a complete reorganization of the hitherto heterogeneous group effected. Mr. Stanton has shown the Martinez of Gabb to consist of two parts, one characteristic Cretaceous and inseparable from the Chico group, the other being more closely related faunally and stratigraphically to the Tejon-Eocene than to the Chico. The upper portion was therefore placed with the Tejon and designated as Lower Tejon. As a possible modification of his classification Mr. Stanton states that, "if more detailed field work makes it desirable to retain the name (Martinez) at all, it should be restricted to the Eocene (upper) portion . . . ."

In the following discussion the name Martinez is applied to that portion of Gabb's Martinez group which remains, after the removal of the Chico-Cretaceous element. The writer's statements are based on observations, extending over a period of several years, made in the typical region for the group, viz., that adjacent to the town of Martinez.

In the hills to the southwest of Martinez strata of unquestioned Chico age, containing a characteristic fauna, occur over a considerable area. In a fine outcrop of compact, bluish sandstone occurring on the west side of Alhambra Valley, and near the top of the Chico, the writer found an abundance of fossils, characteristic of this group, which are listed in the table below, under Locality No. 1. From this point to the east and west the structure of the strata is anticlinal, showing an apparently conformable series up as far as the Miocene on each side.

From the standpoint of stratigraphy, one would hardly be disposed to find fault with Gabb's conception of the Martinez, since in this, the typical locality, the Chico, Martinez, and Tejon, *appear* everywhere to be conformable, while numerous complications of the stratigraphy have still farther increased the difficulty of separating these three groups on stratigraphic grounds.

[1] The Faunal Relations of the Eocene and Upper Cretaceous on the Pacific Coast 17th Ann. Rep. U. S. Geol. Survey, 1895-6.

Lithologically there are some differences between the Martinez and the adjoining formations, the most important of which are the slightly different aspect of its sandstones and the frequent presence in them of considerable quantities of glauconite. The sandstones are often grayish, differing from the yellowish or bluish rocks of the Chico and the massive white to dull red Tejon sandstones. In many places the Martinez contains large quantities of glauconite disseminated evenly through the sandstones in rounded grains of considerable size. Glauconite does not seem to occur at all in the Chico but may possibly be found toward the base of the true Tejon. The truly glauconitic rocks belong principally to the Martinez.

While the group shows little which would serve to separate it stratigraphically or lithologically from the over and underlying formations, its fauna, on which Gabb based his classification, contains numerous elements throwing light on its geologic relations. Between the Chico-Cretaceous and the Miocene there are two distinct faunas present, viz., the Martinez (in part) and Tejon of Gabb, or the Lower and Upper Tejon of Mr. Stanton. As other criteria failed to separate satisfactorily the Chico, Martinez, and Tejon, extensive fossil collections were made by the writer at all possible points. A series of rich localities running across the strike from the Chico to the Tejon furnished the sequence of faunas as shown in the table on pages 770 and 771.

An examination of these lists shows that the lower Martinez beds, as stated by Mr. Stanton, have a fauna distinct from that of the Chico, and that, while the two sets of rocks may seem to be conformable, an unconformity, as yet unobserved, probably exists. There are no species common to localities 1 and 2 excepting *Dentalium Cooperi* which ranges up into the Tejon and appears to be identical with a form occurring in the lowest Miocene. Other localities furnishing a few imperfect fossils are known in beds perhaps somewhat lower down than Locality No. 2 but as yet no distinct overlapping of the two faunas has been discovered.

Locality No. 3, higher up in the group, furnishes a fauna of

TABLE SHOWING CHANGES OF FAUNA FROM CHICO TO TEJON.[1]

	Chico	Martinez	Tejon
LOCALITY NO. 1.—TYPICAL CHICO.			
1 *Corbula cultriformis* Gabb....	*		
2 *Meekia sella* Gabb..........	*		
3 *Meekia navis* Gabb	*		
4 *Meretrix arata* or *fragilis* Gabb	*		
5 *Mytilus quadratus* Gabb......	*		
6 *Mytilus pauperculus* Gabb....	*		
7 *Nucula truncata* Gabb.......	*	*	*
8 *Pecten martinezensis* Gabb ...	*		
9 *Pectunculus Veatchi* Gabb....	*		
10 *Tellina Hoffmanniana* Gabb..	*		
11 *Tellina aequalis* Gabb (?)	*		
12 *Venus varians* Gabb.........	*		
13 *Cinulia obliqua* Gabb........	*		
14 *Cylindrites brevis* Gabb (?)...	*		
15 *Dentalium Cooperi* Gabb.....	*	*	*
16 *Gyrodes expansa* Gabb.......	*		
17 *Perissolax brevirostris* Gabb n. var..................	*		
18 *Pugnellus hamulus* Gabb	*		
19 *Solarium inornatum* Gabb ...	*		
20 *Helicoceras vermicularis* Gabb.	*		
21 Sharks' teeth 2 sp...........	*		
22 Teleost fish scale			
LOCALITY NO. 2.—LOWER MARTINEZ.			
1 *Flabellum Remondianum* Gabb		*	*
2 *Placosmilia* n. sp............		*	
3 *Schizaster* (?) n. sp.........		*	
4 *Arca* n. sp.................		*	
5 *Cardium Cooperi* Gabb......		*	†
6 *Cucullæa Mathewsoni* Gabb...		*	
7 *Leda Gabbi* Conr............		*	*
8 *Lucina* sp.................		*	
9 *Meretrix* sp................		*	
10 *Modiola* n. sp..............		*	
11 *Pholadomya nasuta* Gabb.....		*	
12 *Tapes quadrata* Gabb (*aff.*)...		*	*
13 *Tellina* n. sp..............		*	
14 *Actaeon* (?) n. sp............		*	
15 *Cylichna costata* Gabb........		†	*
16 *Dentalium Cooperi* Gabb	*	*	*
17 *Discohelix* n. sp....		*	
18 *Fusus* n. sp. (*a*)............		*	
19 *Fusus* n. sp. (*b*)............		*	
20 Indet. nov.................		*	
21 *Neptunea mucronata* Gabb....		*	
22 *Perissolax Blakei* Conr. n. var.		*	
23 *Siphonalia lineata* Stanton....		*	
24 *Turritella* sp..............		*	
25 *Urosyca caudata* Gabb.......		*	
26 *Urosyca* n. sp..............		*	
27 *Xenophora* n. sp............		*	
28 Glauconite................			
29 Foraminifera..............			
LOCALITY NO. 3.—UPPER MARTINEZ.			
1 *Arca* n. sp.................		*	
2 *Cardium Cooperi* Gabb......		*	†
3 *Cucullæa Mathewsoni* Gabb..		*	
4 *Leda Gabbi* Conr............		*	*
5 *Modiola ornata* Gabb........		†	*
6 *Pholadomya nasuta* Gabb.....		*	
7 *Solen* n. sp.................		*	
8 *Tellina* (?) *undulifera* Gabb..		*	
9 *Brachysphingus liratus* Gabb.		*	
10 *Bullinula* (?) n. sp...........		*	
11 *Dentalium Cooperi* Gabb.....	*	*	
12 *Fusus* n. sp................		*	
13 *Heteroterma Gabbi* Stanton ...		*	
14 *Perissolax Blakei* Conr. n. var.		*	
15 *Siphonalia lineata* Stanton....		*	
16 *Strepsidura pachecoensis*, Stanton......................		*	
17 *Turritella infragranulata* Gb.		*	
18 *Urosyca caudata* Gabb.......		*	
LOCALITY NO. 4.—NEAR UPPER LIMIT OF MARTINEZ.			
1 Nummuloid		*	
2 *Schizaster* (?) n. sp.........		*	
3 *Cardium Cooperi* Gabb.......		*	†
4 *Cardita Hornii* Gabb........		†	*
5 *Modiola* n. sp..............		*	
6 *Solen* n. sp................		*	
7 *Tellina Hornii* Gabb		†	*
8 *Tellina* n. sp..............		*	
9 *Thracia* (?) n. sp...........		*	
10 *Ampullina striata* Gabb (*conf.*)		*	
11 *Dentalium stramineum* Gabb..	*	*	*
12 *Ficopsis* sp. (near *Remondi*)..		*	*
13 *Megistostoma striata* Gabb....		†	*
14 *Morio* sp. (*tuberculatus?*).....		†	*
15 *Solarium* n. sp..............		*	
16 *Tritonium* n. sp		*	
17 *Tritonium* (?) n. sp		*	
18 *Turris* n. sp..............		*	
19 *Turritella* n. sp. (?)........		*	

[1] An asterisk indicates common or characteristic; a dagger, rare or characteristic of some other horizon.

TABLE.—*Continued.*[1]

	Chico	Martinez	Tejon
LOCALITY NO. 5.—TEJON, A SHORT DISTANCE ABOVE LOCALITY NO. 4.			
1 *Trochosmilia striata* Gabb....			*
2 *Cardium Breweri* Gabb......			*
3 *Cardium Cooperi* Gabb		*	†
4 *Cardita Hornii* Gabb........		†	*
5 *Meretrix Hornii* Gabb.......			*
6 *Meretrix uvasana* Conr......			*
7 *Modiola ornata* Gabb........		†	*
8 *Nucula truncata* Gabb.......	*	*	*
9 *Pectunculus sagittatus* Gabb..			*
10 *Amauropsis alveata* Gabb....			*
11 *Cylichna costata* Gabb........		†	*
12 *Conus Remondi* Gabb........			*
13 *Dentalium Cooperi* Gabb....	*	*	*
14 *Ficopsis Remondi* Gabb.......			*
15 *Ficopsis* sp. (near *Remondi*)...		*	*
16 *Morio* sp. (*tuberculatus*)......		†	*
17 *Perissolax Blakei* Conr. Typ. var......................			*
18 *Rimelia canalifera* Gabb.....			*
19 *Turritella uvasana* Conr.....			*
20 *Oliverato californica* Cooper ..			*

the same type as that of No. 2 but containing some forms as *Tellina* (?) *undulifera*, *Turritella infragranulata*, and *Brachysphingus liratus*, not present in the lower beds. One minute specimen of the characteristic Tejon form, *Modiola ornata*, was obtained at this horizon.

At Locality No. 4, near the upper limit of the Martinez, about one third of the fauna is composed of species known from the Tejon. Of these forms *Dentalium stramineum* is a long-lived species ranging from Chico to Tejon. *Cardium Cooperi*, though known from Tejon beds, is not a common or characteristic fossil of that group, while it ranges through the Martinez and is one of its most characteristic species. The *Cardita* belongs to the Tejon species described as *Hornii* by Gabb but may be a new variety. *Megistostoma striata*, *Tellina Hornii* and the *Morio* seem to be typical Tejon forms and are not found below the uppermost beds of the Martinez. The *Ficopsis* sp. is a form known from the Upper Martinez and Lower Tejon. Imperfect specimens of a foraminifer related to *Nummulites* are abundant at this locality. Though the fauna at this horizon is certainly closely related to that of the true Tejon, only three good species are common or characteristic forms in that group.

[1] An asterisk indicates common or characteristic; a dagger, rare or characteristic of some other horizon.

At Locality 5, a short distance (less than 100 feet) above No. 4, fossils of the well-marked fauna to which Gabb gave the name Tejon are found in abundance, *Cardium Cooperi* being the only really characteristic Martinez species associated with them. No localities showing more gradation between the Martinez and Tejon faunas than those here discussed have so far been discovered by the writer.

Numerous other collections made between Localities 2 and 3 and between 3 and 4 furnished gradations from one to the other, with some additional species not mentioned in the foregoing lists.

In the following table there are placed together all of the species known to the writer from the strata between the Chico and the true Tejon near Martinez, along with those which have been collected elsewhere by Mr. Stanton, in beds of the same age. A study of this list shows clearly that the fauna is a unit, and that it is quite distinct from both the Chico and the Tejon, though it grades to some extent into the latter.

The existence between the Chico and the Tejon of a fauna not belonging clearly to either group, was evidently not unknown to Gabb, and this fauna formed the real basis of his Martinez. Unfortunately the involved stratigraphy led him or his collectors into the error of supposing that certain Chico forms belonged in the same horizon with Martinez species, while the first error led to a second, viz., the belief that, since Chico forms were present in his Martinez fauna, the whole group might be found later to represent a subdivision of the Chico. As has been shown in the comparison of faunas, there can be little doubt that the Chico group is widely separated from what is here called Martinez.

In considering the relations of the Martinez to the Tejon, it might be well to determine first what was intended in the original definition of the Tejon group and what it really is. The name was proposed by Gabb on *palæontological grounds* for a set of rocks, supposed by him to be Cretaceous, but now generally regarded as Eocene, "most extensively developed in the vicinity

THE FAUNA OF THE MARTINEZ GROUP WITH GEOLOGICAL RANGE OF THE SPECIES.[1]

	Chico	Martinez	Tejon		Chico	Martinez	Tejon
1 Foraminifera Nummuloid		*		36 *Dentalium stramineum* Gabb	*	*	*
2 Foraminifera 3 sp. Indet.....				37 *Discohelix* n. sp...........		*	
3 *Flabellum Remondianum* Gabb....................		*	*	38 *Ficopsis* sp (near *Remondi*)...		*	*
4 *Placosmilia* n. sp...........		*		39 *Fusus* n. sp (*a*)		*	
5 *Schizaster* (?) n. sp..........		*		40 *Fusus* n. sp. (*b*)		*	
6 *Terebratula tejonensis* Stanton		*		41 *Heteroterma Gabbi* Stanton...		*	
7 *Arca* n. sp.................		*		42 *Heteroterma striata* Stanton..		*	
8 *Cardita Hornii* Gabb........		†	*	43 *Heteroterma trochoidea* Gabb.		(?)	
9 *Cardium Cooperi* Gabb.......		*	†	44 Indet. nov.................		*	
10 *Crassatella unioides* Stanton ..		*		45 *Lunatia Hornii* Gabb.		†	*
11 *Cucullœa Mathewsoni* Gabb...		*		46 *Megistostoma striata* Gabb...		†	*
12 *Leda alœformis* Gabb........		*		47 *Morio* sp. *tuberculatus?*......		†	*
13 *Leda Gabbi* Conr............		*	*	48 *Natica* sp..................			
14 *Lima multiradiata* Gabb.....		*		49 *Neptunea mucronta* Gabb....		*	
15 *Lucina Turneri* Stanton.....		*		50 *Perissolax Blakei* Conr. nov. var....................		*	
16 *Meretrix* sp................		*		51 *Siphonalia lineata* Stanton...		*	
17 *Modiola* n. sp...............		*		52 *Solarium* n. sp		*	
18 *Modiola ornata* Gabb........		†	*	53 *Stripsidura pachecoensis* Stanton....................		*	
19 *Nucula truncata* Gabb......	*	*	*	54 *Tritonium* n. sp. (*a*)		*	
20 *Pectunculus Veatchi* var. *major* Stanton.................		*		55 *Tritonium* (?) n. sp. (*b*).....		*	
21 *Pholadomya nasuta* Gabb.....		*		56 *Turbinella crassitesta* Gabb ..		*	
22 *Plicatula ostreiformis* Stanton		*		57 *Turritella infragranulata* Gabb		*	
23 *Solen* n. sp................		*		58 *Turritella pachecoensis* Stanton		*	
24 *Tapes quadrata* Gabb (*aff.*) ...		*	*	59 *Turritella* n. sp. (?)........			
25 *Tellina* n. sp...............		*		60 *Turris* n. sp..............		*	
26 *Tellina Hornii* Gabb		*	*	61 *Urosyca caudata* Gabb.......		*	
27 *Tellina* (?) *undulifera* Gabb..		*		62 *Urosyca* n. sp		*	
28 *Teredo* (?).................				63 *Xenophora* n. sp............		*	
29 *Thracia* (?) n. sp............		*		64 Crustacean remains, brachyuran....................		*	
30 *Actaeon* (?) n. sp............		*		65 Crustacean remains, macruran			
31 *Ampullina striata* Gabb (*conf.*)		*		66 *Serpula*			
32 *Brachysphingus liratus* Gabb.		*					
33 *Bullinula* (?) n. sp..........		*					
34 *Cylichna costata* Gabb........		†	*				
35 *Dentalium Cooperi* Gabb.....	*	*	*				

of Fort Tejon and about Martinez." It was stated[2] to contain "a large and highly characteristic series of fossils, the larger part peculiar to itself, while a considerable percentage is found

[1] An asterisk indicates common or characteristic; a dagger, rare or characteristic of some other horizon.

[2] Rep. Geol. Surv. Cal. Palæontology, Vol. II, p. 13 of Preface.

extending below into the next group, and several species still farther down into the Chico group." Since Gabb's work was published the Tejon has been recognized at numerous points on the Pacific coast, outside the limits of its distribution as known to him, and has always been found to contain an easily recognized fauna, of which a number of the most common and characteristic forms are found in the list of species from locality No. 5. As may be seen in the last quotation, the true relation of the Martinez to the Tejon, as shown by the partial mingling of species, was not unknown to Gabb.

In the vicinity of the town of Martinez, the Martinez and Tejon groups form an apparently conformable series between two and three thousand feet in thickness and about equally divided between the two. The faunas, though overlapping, are in the main quite distinct and no great difficulty has been experienced by the writer in separating the groups on this basis. While some intermingling of species exists, it is not greater than we should expect to find in adjoining groups or periods. It should also be observed that the beds with a Tejon-like Martinez fauna and those containing an assemblage of characteristic Tejon forms are comparatively close together. The change from one fauna to the other may possibly have taken place in a short time by migration, but we cannot assert positively as yet that the apparent conformity of the beds is a real one, sedimentation may have been interrupted between the times of deposition of the two groups. It is at any rate quite clear that the two sets of strata, or two faunas, while belonging perhaps to the same series, represent different periods in the geological history of California, periods quite as distinct, so far as faunal evidence is concerned, as the Miocene and Pliocene, or the Pliocene and Quaternary. The upper division of this series has already, on the grounds of its characteristic fauna, been named the Tejon. To a mixed group of rocks, to which the fauna here called the Martinez gave individuality, the name Martinez group was applied by Gabb. It seems desirable, after having cut out the Chico portion of Gabb's Martinez which was probably not the one on which he based the group,

to apply the name used by him to the distinct fauna or group which remains. As to the nomenclature of the supposedly conformable series, including the Martinez and Tejon, it seems best to apply to it for the present the term Martinez-Tejon series, though future convenience may demand a special series name. To apply the name Tejon to the whole series would be to modify considerably the meaning of this term as used originally, and would have besides the fault of taking the name from a smaller division to apply it to a larger, leaving the first to be virtually renamed.

In conclusion, the group under consideration might be characterized as follows: The Martinez group, comprising in the typical locality between one and two thousand feet of sandstones, shales, and glauconitic sands, forms the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty species, of which the greater portion is peculiar to itself. A number of its species range up into the Tejon and a very few long-lived forms are known to occur also in the Chico. Since the Martinez and Chico are faunally only distantly related it is probable that an unconformity exists between them. Though satisfactory correlation of Californian formations with the subdivisions of the standard geological scale can be accomplished only when the local scale is fully worked out, we may, for the present at least, accept Mr. Stanton's correlation of the Martinez with a portion of the Eocene.

John C. Merriam.

Berkeley, California.

STUDIES IN THE SO-CALLED PORPHYRITIC GNEISS OF NEW HAMPSHIRE. II.

Contact Metamorphism.— The endomorphic changes wrought by the granite intrusions are relatively slight. Thus the biotite-gneiss and hornblende-gneiss southwest of Lake Wakawan have the same mineralogical composition at the contact as they have a quarter of a mile away from it along the strike. On Spindle Point, gneisses of like nature show the only exomorphic change discovered throughout the whole terrane of the Lake Winnipiseogee gneiss. Yet even this is a doubtful case, since the only evidence is the presence of some sillimanite needles and a few garnets in the schist near the granite. Again, the interbedded biotite-gneiss, muscovite-biotite-gneiss, and actinolite-gneiss, at the outlet of Little Squam Lake, are practically unaffected by the granite. The same is true of the large biotite-gneiss-inclusion on the north side of Beech Hill, as well as of the whole contact-line of the Montalban group.

The schists on Saddle Hill exhibit the best metamorphic belt which appears in the Winnipiseogee area. Specimens of the country-rock were taken at localities from one to eight hundred feet from the contact, and in all of them the country-rock proves to be a typical muscovite-biotite-schist with accessory sillimanite in long needles. Inside that zone toward the granite, however, a pronounced metamorphic aureole encloses phases of the terrane which represent important modifications of the schist. One of them, some eighty feet from the contact, is a hornfels largely made up of zoisite and andalusite (?) with quartz and magnetite. Another, four feet from the granite, is a compact mica-schist richly charged with garnets; while within five inches of the contact this garnetiferous schist has absorbed a large amount of orthoclase and plagioclase which seem to have been derived from the neighboring granite.

The Ashuelot area is even more nearly devoid of distinct zones of contact-alteration. Several suites of specimens were taken across the marginal belt of schists at several different localities, but in none of them was a definite alteration of mineral content observable, as one goes toward the igneous rock. While the Coös schists are highly garnetiferous at the contact, they are often just as metamorphic in habit a mile or more from the granite. Interlaminated actinolite-schists are abundant among the common mica-schists of the area. They show no change at the contact. The Bethlehem gneiss is often garnetiferous, and in some slides the garnets are seen to be larger and more idiomorphic near the granite than away from it. Apart from this fact, one would not suspect from an inspection of the marginal alterations that the porphyritic granite was once an igneous body intruded in these same rocks in a molten state.

Finally, it would be difficult to point to any particular part of the Main area as exhibiting metamorphic phases in the schistose country-rock of the porphyritic granite which could not have been produced before the granite was erupted. One hundred and fifty feet from the great Greenfield sheet a typical quartz-garnet-hornfels can be found, but from that rock to the granite one passes over the typical biotite-muscovite-schist of the region. The latter itself may be garnetiferous. It does not, however, differ from similar phases of the ferruginous rocks several miles from the contact. North of Henniker there outcrops another hornfels at a contact with a prophyritic granite apophysis and about 50 feet from the molar contact. It is a compact aggregate of quartz and garnet with a large admixture of a colorless pyroxene and a little accessory plagioclase and muscovite. Notwithstanding this kind of association, these and other examples cannot as yet with safety be considered as contact phases, nor do they afford positive evidence of an eruptive origin for the porphyritic granite.

The small amount of exomorphic change in the contact-belt is that which might be expected from the conditions of the eruptions. It is well known that, other things being equal, acidic

igneous rocks are less likely to be altered by intrusive masses than are the more basic rocks. In the same way sedimentary rocks are in general more susceptible to contact metamorphism than the crystalline chists or than igneous rocks.[1] Pohlig noted important differential effects of the trachyte in the Siebengebirge. Fragments of gneiss enclosed in the eruptive rock were relatively unchanged as compared with inclusions of clay-slate in which andalusite and other metamorphic minerals were developed.[2] Lehmann has described granulite inclusions in the granite of Markersdorf which he found to be entirely unchanged by the granite.[3] No student of contact-belts needs, however, to be reminded that in them there is pronounced selective metamorphism depending upon the nature of the rocks invaded. Those which have advanced furthest in the direction of mineralogical stability will usually be the rocks which are least altered. If, then, there had been regional metamorphism of the country-rock before a given intrusion occurred, such terranes will tend to be without distinct zones of alteration. Such is the case with the New Hampshire rocks. In the sequel the chief evidence for this conclusion will be given, but we can anticipate somewhat by stating the fact that the same series of schists which are cut by the porphyritic granite are just as thoroughly crystalline many miles from the porphyritic granite as they are in its immediate vicinity. Moreover, they attained this crystalline character in the process of mountain-building and not by any kind of local thermo metamorphism induced by underlying areas of the porphyritic granite.[4] The eminent schistosity of these rocks was anterior to the granitic intrusion, and it is an effect concomitant with the recrystallization. Thus it was a series of terranes already regionally metamorphosed that were cut by the porphyritic granite. They had reached a state of approximate mineralogical equilibrium and but little rearrangement of the constituent elements was possible by mere contact action.

[1] Cf. HUDLESTON, Address Pres. Geol. Soc., 1894; Q. J. Geol. Soc., p. 121.

[2] Tschermak's Mitth., 1880–1, p. 353.

[3] Untersuch. über die Entsteh., der altkryst. Schiefergesteine, 1884, p. 7.

[4] Cf. BARROW, Q. J. Geol. Soc., 1893, p. 352.

Moreover, at Fitzwilliam, where the inclusions of the neighboring biotite-gneiss are extremely well exposed, there does not seem to be the slightest change in the horses. Yet there can be no doubt that the porphyritic granite is here distinctly eruptive in the gneiss. In the same way, the ancient granitite described on the west and northwest of the village of Antrim has produced no material alteration in the composition of the schist inclusions, for in that feature they are identical with their parent terrane for several miles from the contact.

It seems reasonable, then, to conclude from the brief account of exomorphic contact-phenomena just given that they do not invalidate the argument for the porphyritic granite's being eruptive. It means that the conditions were not such as to permit of the development of the well-marked metamorphic aureoles which one might expect in invaded terranes composed of relatively unaltered rocks.

Endomorphic changes.— More often than not where the actual contact between the porphyrictic granite and the older formations appears, there is practically little change either in the composition or grain of the granite. This fact is characteristic of apophyses as well as of the main body. In the Winnipiseogee and Main areas particularly, the feldspaı phenocrysts and their matrix are remarkably persistent in the size of individual minerals. The reader will remember that a broad band of the porphyritic granite with rare phenocrysts appears on the western side of the Ashuelot area, and again that, on the eastern side, there is evidence of fine-graining in the Bethlehem gneiss-contact which can hardly be explained except as belonging to a chilled phase of the igneous rock. It is true, however, that this phenomenon is, on the whole, rather the exception than the rule in the different areas. We cannot but think that the invaded schists must have been at a high temperature themselves when the granite was intruded. Witness the widespread zones of passage between the two. The great coarseness of the matrix shows that the granite was long in crystallizing and in that process would naturally lose much heat to the surrounding rocks.

Thus the latter could not in the final stage of consolidation cause a serious differential cooling in the marginal part of the granitic magma. That there was some influence exerted upon the igneous rock is indisputable. Almost universally thin sections of the contact-zone exhibit a very marked granophyric intergrowth of the quartz and feldspar of the matrix. This micrographic development is quite independent of that noted as common about the phenocrysts, and is quantitatively much superior in value to the latter. The occurrence of the graphic structure in the matrix is usually restricted to the contact-zone of not more than a few inches or feet in width. It is noteworthy, however, that in parts of the Ashuelot area where there are evidences of some crushing, this structure is found in various parts of the coarse matrix, though far from a contact. It doubtless originated as a result of rearrangement during the period of stress which the rock has here undergone.

The origin of the foliation in the porphyritic granite.—It is now well established that gneisses may belong to three classes which in the words of Gregory[1] may be named metapyrigen-gneisses, clastic-gneisses, and fluxion-gneisses. The first kind is produced by the pressure-metamorphism of igneous rocks, the second by the complete alteration of sediments. The third division has its origin in molten rock-magmas which have undergone "fluxional movements anterior to complete consolidation in a mass not perfectly homogeneous."[2] The porphyritic granite of New Hampshire owes its foliated structure to the same cause as that of fluxion-gneisses. In short, this porphyritic gneiss is a porphyritic granite with a flow-structure. The parallelism among the constituents was assumed when the rock was not yet fully crystallized out and cannot thus be referred to any metamorphic result of mountain-building acting on an already solidified mass. It is a primary structure. Since this fact is not as yet demonstrated in what has been said, and since we are dealing with a

[1] Q. J. Geol. Soc., 1894, p. 266.

[2] T. G. BONNEY, Some Notes on Gneiss, Geol. Mag., 1894, p. 118. Cf. HILL and BONNEY, Q. J. Geol. Soc., 1892, p. 137.

great terrane characterized everywhere by this foliation which has been the subject of serious misapprehension among early investigators in the state, we shall go into some detail to establish this position.

It was not until the next generation after von Buch [1] described flow-structure in lavas that the phenomenon was studied with reference to the origin of gneisses. Scrope [2] in 1840 and Darwin [3] in 1844, closely followed by Naumann,[4] first laid emphasis on the truth that "dragging movements" on a cooling granitic magma may lead to the formation of gneiss. Since that time, a host of observations have confirmed their idea so completely that it is now possible to frame the most important criteria which ought to be applied to a problematical case, and, if satisfied, should enforce belief in the gneissic structure of that particular instance being of fluxional origin. It is proposed to consider briefly these criteria with respect to their validity and to their relation to our particular problem.

1. Since the fluxion-structure is due to differential stress, we should expect some parts of a mass, to display a greater excellence of the foliation than others. There will be zones of relatively rapid movement and zones of more static conditions; at least during the geological movement of final consolidation. Thus, we may expect to find transitions from trendless granite to well-foliated granite or gneiss.[5] We have already seen how abundantly this change is exemplified in all the areas of the porphyritic granite. Both of the State Surveys noted this relation between the massive and foliated phases.[6] The earlier one seized upon the former as indicating simply a granite, the second

[1] Geognost. Beobacht. auf Reisen durch Deutschland und Italien, 1809, II, p. 209.

[2] Trans. Geol. Soc., 2d ser., II, p. 228.

[3] Geological Observations, etc., 1st ed., 1844, ch. iii.

[4] Neu. Jahrb., 1847, p. 297. Q. J. Geol. Soc., Notices of Memoirs, p. 1.

[5] Michel Lévy, Bull. Soc. Geol. de France, 1878–9, p. 852. McMahon, The Gneissose-Granite of the Himalayas. Geol. Mag., 1887, p. 214. *Ibid.*, 1888, p. 63. Harker and Marr, The Shap Granite, etc. Q. J. Geol. Soc., 1891, XLVII, p. 284 Emerson, Bull. Geol. Soc. Am., I, 1890, p. 559.

[6] Note, Geol. of New Hampshire, Vol. II, p. 99.

survey regarded the non-foliated parts as fused parts of a series of altered sediments.

2. The parallel structure ought to be best assumed along the contact, because there the essential condition of an appropriate viscidity will be assumed within a zone which has a dominant trend. Where the interaction effects of more than two cooling surfaces meet, as they do in a mass of considerable breadth, there is a tendency towards the obliteration of parallelism induced in any one zone of chilling at a plane of contact. Convection currents will further complicate the flow-structure and to a greater extent in the hotter core of an intrusive mass than in the chilled zone. For these reasons parallelism among the constituent minerals should be most clearly exhibited along the boundaries where the structure-planes of the igneous mass will accord in direction with the plane of contact. The central area may either lose any incipient foliation or show sudden irregular changes of strike and dip of fluxional planes which do exist. In other words, wherever else it may appear, the fluxional structure is to be looked for chiefly at the margins.[1]

[1] BRÖGGER (Die Silurischen Etagen 2 und 3; Kristiania, 1882, pp. 325, 326), describes the endomorphic zone of contact of his granitic and syenitic eruptives as possessing a parallel structure "wodurch gestreifte Gesteine, bisweilen wie echte krystallinische Schiefer aussehen. It is parallel to the irregular boundaries of the igneous rocks.

McMAHON, Note on the Foliation of the Lizard Gabbro; Geol. Mag., 1887, p. 76.

BARROIS states that in the granulites of Morbihan the parallelism is most perfect when the contact-line is in the strike of the enclosing strata. In such parallel contacts, the granulite is apt to change to a "granulite porphyroïde, à grands éléments, alignés fluidalement." In "contacts perpendiculaires" the rock has an aplitic phase in which the crystalline constituents have regular geometric forms. He considers that such differences in the intruded granite depend on the country-rock as an agent chemically inactive but "diversement conducteur de la chaleur et de la pression." Sur les modifications endomorphes des massifs granulitiques du Morbihan; Comptes Rendus, CVI, 1888, p. 428.

GEIKIE, A., The History of Volcanic Action during the Tertiary Period in the British Isles; Trans. Roy. Soc. Edin., 1888, p. 37.

BARLOW, On the Contact of the Huronian and Laurentian Rocks North of Lake Huron, Am. Geol., VI, 1890, p. 22.

SMITH, W. H. C., Ann. Rep. Geo. Surv. Canada, 1890-1, map.

GREGORY, J. W., The Waldensian Gneisses and their Place in the Cottian

The reader will remember how often this principle was illustrated in our detailed account of contact-phenomena. It undoubtedly explained the greater perfection of the foliation in the long and narrow Winnipiseogee area than that in the broadly eliptical Ashuelot area or Main area. At the Bennington reservoir in the large size of the feldspar phenocrysts and their definite orientation with respect to the adjacent contact we have a good example of what characterizes the endomorphic zone of the Main area throughout the eastern contact as mapped. Within the zone the structure is much less determinate. Again, on Sandwich Mountain the porphyritic granite in and about the "permeation-area" described above, is largely granitic with the exception of those parts which display the fluxional habit about the horses. We are not without suggestion that the sudden changes of dip and strike within the cores of the igneous masses are largely the result of convection acting with massive pressure in the still viscid rock-body. Two miles from Weirs, on the highway to Meredith village, several outcrops appear in a clear field some three hundred yards to the right of the road. At one of these, a well-marked anticlinal arrangement can be observed in typical porphyritic granite. This structure is not part of a general system of parallel folds, nor of folds with any recognizable relation to the behavior of solid rock acted upon by lateral force. It is rather to be correlated with the irregular flow-structure assumed in the internal parts of many rhyolites; the well-known "felsites" of eastern Massachusetts furnish a good example.[1]

3. An analogous appearance will tend to characterize the margins between the intrusive rock and any foreign bodies which

Sequence; Q. J. Geol. Soc., 1894, p. 249. On page 265 the author says of the foliation in these Alpine gneisses that it is "a contact-fluxion, and has no connection with the dynamo-metamorphism of the district. This marginal orientation also occurs on a microscopic scale. Mr. C. L. Whittle has described good examples in the contacts of the Connecticut Triassic lavas.

BONNEY, T. G., Some Notes on Gneiss; Geol. Mag., 1894, p. 118.

[1]Cf. MEHNER, "Fluctuationstructur" described in certain of "die schiefrigen Porphyren" of Westphalia; Tsch. Mitth., 1877, p. 177.

are caught up from the surrounding terranes.[1] In many cases, however, it is due not only to differential cooling, but to the pulling of the horses along in the direction of the migrating viscid magna. Such is the case with the examples of the circumferential arrangement of feldspars noted on Sandwich Mountain, on Saddle Hill, and in the Fitzwilliam area, and elsewhere.

4. Many observers have described the orientation of horses parallel to the margins of contact in cases where the inclusions have distinct elongated form.[2] The latter condition is usually furnished in the case of fragments derived from a country-rock with plane-parallel-structure. Consequently, we can understand this very general marginal arrangement described in all of the principal areas.[3]

5. The greater the heterogeneity among the constituents of the igneous body at the time of proximate consolidation, the more pronounced will be the flow-structure.[4] As suggested by Bonney,[1] horses may be melted up and thus give local variations in the mineralogical constitution of the igneous body. "Banding" is sometimes produced by the imperfect mixing of more

[1] LAWSON, The Geology of the Rainy Lake Region; Ann. Rep. Geol. Surv. Canada, 1887-8, F, 137-138. BARLOW, op. cit., p. 29. DAKYNS and TEALL, On the Plutonic Rocks of Garabal Hill and Meall Breac; Q. J. Geol. Soc., 1892, p. 106. KOTO, B., The Archæan Formation of the Abukuma Plateau; Jour. Coll. Sci. Imp. Univ., Tokio, 1893, p. 288. GREGORY, Q. J. Geol. Soc. 1894, p. 242.

[2] DUROCHER, Mém. de la Soc. Géol. de France, 2^e sér., t. VI. See his descriptions of several gneiss-granite contacts in Scandinavia; LEHMANN, Untersuchungen über die Entstehung der altkryst. Schiefergesteine. Bonn, 1884, pp. 16, 21; GEIKIE, A., op. cit., p. 39; GRANT, U. S., Field observations on certain granitic areas in northeastern Minnesota; 20th Ann. Rep. Minn. Surv., 1891, p. 40.

[3] Cf. EMERSON, Bull. Geol. Soc. Am., I, 1890, p. 559.

[4] Geol. Mag., 1894, p. 119. Cf. BONNEY, *ibid.*, 1894, p. 118. C. CHELIUS has recently described a stage leading to the complete fusion of enclosed masses, which is of interest. In this case granite cuts diorite and includes so many lenses of the latter in parallel arrangement as to simulate a "grobflaseriger gneiss." Notizbl. d. Ver. f. Erdk. Darmstadt, IV, Folge, 14 Heft, 3–8, 1893. Ref. in Neu Jahrb., 1895, p. 72.

J. J. SEDERHOLM speaks of "Schlieren" rich in mica and garnets in the "druckschieferiger Granit" of Finland. They are taken to represent remnants of schist-inclusions which have been dynamically metamorphosed. Om Börggrunden i Södra Finland, 1893. Ref. in Neu. Jahrb., 1895, p. 335.

than one phase of a magma.[1] It is conceivable that it might be locally brought about by the pulling out of basic segregations in a plutonic rock by mechanical force operating during or after complete consolidation.

On the road along the north shore of Wickwas pond a striking phase of the porphyritic granite was found which had been discovered before but never in such perfect development. It forms a strongly schistose mass a few inches thick which lies parallel to the foliation of the normal rock. Composed largely of brown biotite with here and there a large feldspar phenocryst, it is very different in appearance. With the biotite large apatites and considerable masses of titanite and magnetite make up the groundmass. This band had much the appearance of a shear-zone, like that described in the crystallines of the Malvern Hills.[2] But the microscope discloses no strong evidences of crushing in the feldspars which are clearly original or primary in their nature. Now there are plenty of cases on record where biotite segregations in granitic rocks grow to large size. Those at Graniteville, Missouri, vary from a few inches to five feet or more in diameter.[3] It may be that this and similar local bands in the rock in question are due to the tailing out of such segregations before the final solidification of the whole rock had set in. The resulting bands would thus be parallel to neighboring structure-planes and take their place as primary elements in a fluxional mass.

But the most favorable chance for the exhibition of a parallel structure over large areas would be given in cases where there is more than one generation of minerals; *i. e.*, in porphyritic rocks. Such, indeed, has been the character of most of the plutonic rocks where extensive flow-structure has been described. The large size of the phenocrysts of the porphyritic granite is one of the chief conditions leading to this peculiar and widespread foliation. Possessed of large growth before the final magmatic crystallization set in, each feldspar phenocryst was, as it were,

[1] HARKER and MARR, Q. J. Geol. Soc., 1891, p. 283; A. GEIKIE and TEALL, *ibid.*, 1894, p. 656.

[2] Q. J. Geol. Soc., 1889, p. 477.

[3] Geol. Surv. Missouri, Ann. Rep., VIII, 1894, p. 154.

of the nature of a foreign body embedded in the matrix. Thus, it would behave in the same manner as the truly exotic inclusion and a conspicuous alignment would result. It was observed in the field that, as a rule, the greater the dimensions of the phenocrysts, the more clearly was the structure displayed.

It is clear that the porphyritic granite with its elongate feldspar phenocrysts abundantly fulfills this criterion. In fact, the study of it suggests that plutonic rocks would more generally show a flow-structure were their constituents more varied in shape and relative size from the usual forms.

Quite rarely a broad banding is observable which is the result of the juxtaposition of layers containing different proportions of the phenocrysts.[1]

6. The negative criterion is valuable and in this New Hampshire case is most conclusive. If it can be shown that mountain-building could not induce the parallel structure in any secondary fashion, *i. e.*, by the pressure-metamorphism of consolidated, igneous or sedimentary rocks, we can fairly assume that the only other recognized cause has been operative. The evidence necessary therefore is threefold.

First, it may be derived from the study of foreign inclusions. The schistosity of the horses in all the observed localities where they occur within the porphyritic granite was evidently produced before the existence of that rock in its present state of crystallization. In practically all cases where comparison was possible, the excellence of this structure in any one inclusion was reflected in its parent - terrane. As the one varied from massive to schistose with a high degree of fissility, so did the other. Now the perfection of the schistosity was found to be irrespective of the attitude of the horses, *i. e.*, whether they were in parallel arrangement or not. Callaway used the correlative of this principle as an aid in determining the nature of the foliated granites of Northern Donegal.[2] He finds in them inclusions of massive diorites. His conclusion is, that on any theory of a

[1] Cf. G. H. Williams, Bull. U. S. Geol. Surv., No. 28, p. 26.

[2] Reade, Origin of Mountain Ranges, p. 139.

mechanical origin for the foliation, it would be "hard to explain the escape of the diorite inclusions from the same influence." But if the intrusion of the porphyritic granite followed the period of plication and metamorphism, we should expect it to follow commonly the structural planes of the preëxisting schists.[1] Again referring to our detailed description of contacts in the three large areas, it will be seen how commonly this is the case. The intrusions are batholitic in their nature. They entered the overlying rocks by melting[2] their way through the axial zones of flexures. It is for this reason that the general distribution of these granite bodies is along the strike of terranes in this part of New Hampshire. The equivalence of strike and dip in the region in the narrow part of the "Fish-hook" north of Squam Lake between the foliated igneous rock and the adjacent schists is especially conspicuous.[3] Such pronounced apparent conformity is probably owing to an exchanging of the usual batholitic form of intrusion for a sill or sheet-form.

Secondly, the study of apophyses will be of much consequence. If we there see parallelism of the minerals composing the intruded tongue to its walls, no matter what the compass-direction of the apophysis may be, it is evident that the structure cannot be referred to mechanical deformation applied after the cooling of the whole intrusive mass.[4] Scheerer early

[1] See GÜMBEL, op. cit., p. 522, 523, 524. He describes "Lagergranite" intruded into various schists. It is rather remarkable that his "Krystallgranit" of Bavaria does not possess a decided flow-structure. The rock is very similar to the porphyritic granite otherwise. Cf. also LAWSON, Ann. Rep. Geol. Surv. Canada, 1885, CC, p. 73, LEHMANN, op. cit., pp. 10, 23; WILLIAMS, G. H., Proc. A. A. A. S., 1887, XXXVI; Sect. E, p. 225; CALLAWAY, Geol. Mag., 1887, p. 354; LAWSON, Ann. Rep. Geol. Surv. Canada, 1887–8, F, p. 32; DANZIG, Mitth. aus dem Min. Inst. der Univ. Keil Bd. I. heft 1, 1888, p. 66; BARLOW, Am. Geol., VI, 1890, pp. 21–22; HARKER and MARR, op. cit., p. 284; ADAMS, Jour. of Geol., 1893, p. 334: SMITH W. H. C., Bull. Geol. Soc. Am., 1893, p. 338.

[2] From the author's previous statements there is no evidence that melting took place in connection with these intrusions. [ED.

[3] See the map of Hunter's Island by Mr. W. H. C. SMITH, which shows a very remarkable parallelism of the foliation in his "granite gneiss" with the strike of the enclosing schists. Ann. Rep. Geol. Surv. Canada, 1890–1.

[4] LAWSON, The Geology of the Lake of the Woods Region; Ann. Rep. Geol.

described an occurrence of the opposite of this.[1] He determined that the red gneiss of the Erzgebirge is plainly eruptive into the gray gneiss. The apophyses of the former have a distinct parallel arrangement among the constituents. It is, however, not parallel to the walls, but inclined to them. He, hence, concludes that it is due to pressure exerted after the consolidation of the ancient granite.[2] That the apophyses should be as coarsely porphyritic as the main body, is of itself a strong suggestion of the exotic origin of the latter.[3] As we have seen, such is the case with the porphyritic granite, and in many instances, as on Saddle Hill, on Sandwich Mountain, in the Greenfield dike, and at Fitzwilliam, the apophyses have a more or less well-developed foliation, parallel to the walls and transverse to the structure-planes of the schists.

Lastly, while the porphyritic granite shows in certain areas evidence of strain, there is none of that very intense crushing which might be looked for if the foliation were of a mountain-built origin.[4] The signs of pressure in some of the phenocrysts may be due to the shearing set up among them in the tough, but still viscid magma, just on the instant of final consolidation. At the south end of the Ashuelot area we have the most schistose phase of the rock. It has evidently been squeezed to some extent. It is crumpled and even changed to an augen-gneiss whose lenticular feldspars represent the idiomorphic phenocrysts of the original rock.[5] Small faults of a half foot throw were observed in the Winnipiseogee area, just

Surv. Canada, 1885, CC. p. 83, DANZIG, Ueber die eruptive Natur gewisser Gneisse sowie des Granulits im sächsischen Mittelgebirge; Mitth. aus dem min. Inst. der Univ. Kiel. Bd. I, Heft 1, 1888, p. 67. REUSCH, Neu. Jahrb., Beil. Bd, V., Heft 1. 1887, p. 57.

[1] Die Gneisse des sächsischen Erzgebirge; Zeit. d. d. geol. Ges., 1862, pp. 122–123.

[2] Credner attempted to prove that the red gneiss of the Erzgebirge is of sedimentary origin and not eruptive, as held by von Cotta, Scheerer, Stelzner, and others. Zeit. d. d. geol. Ges., 1877, p. 757.

[3] Cf. McMAHON, Geol. Mag., 1888, p. 63; Q. J. Geol. Soc., 1893, p. 357.

[4] Cf. LAWSON, The Geology of the Rainy Lake Region, Ann. Rep. Geol. Surv. Canada, 1887–8, F, pp. 137–138.

[5] Cf. HAWES, Geol. of N. H., III, p. 214.

north of Wickwas pond. But there is nothing to indicate that any batholite as a whole has undergone any such enormous stresses as have affected the anorthosite of Canada, the protogine of the Alps, or even the gneisses of the Malvern hills.[1] Under the microscope the New Hampshire rock always shows that the essential minerals crystallized in place and that they have only been affected, except locality, by moderate pressures.

From the complete satisfaction of these several criteria one cannot escape the conviction that the foliation of the porphyritic granite has nothing to do with stratification, and has not been caused by the alignment of the constituents in a time of pressure metamorphism acting on a consolidated rock.

The significance of the uniformity of the porphyritic granite and its wide geological distribution.— One of the most striking characteristics of the porphyritic granite is the lithological sameness which pertains to it to a great degree throughout all the areas examined. This property is retained irrespectively of the nature of the rock-terranes which it invades. From the many examples of endomorphic changes induced in plutonic rocks by the melting up of foreign inclusions, we have selected a few which are described in the annexed footnote.[2] In view of this principle,

[1] CALLAWAY, Q. J. Geol. Soc., 1887, p. 525.

[2] Michael Lévy finds that by an endogenous action granulite cutting diabases and diorites is enriched in plagioclase at the contact (Bull. de la Soc. Géol. de France 1882–3, p. 296). Lehmann states that where the granitite of Döbeln is intruded into biotite-bearing rock, it is practically unchanged, but when it cuts in contact with sericitic schists, siricite is an important constituent (Untersuch. über Ent. d. altkryst. Schiefergesteine, Bonn, 1884, p. 19). Again, on classic ground, Lawson determines his Rainy Lake eruptive rock to be a quartzose biotite-granite gneiss where it comes in contact with quartz porphyries, yet the same rock-body cutting the more basic hornblende schists becomes a hornblende syenite with little quartz (Ann. Rep. Geol. Surv. Canada, 1887–8, F, 31). In one of the great batholites of western Massachusetts, Emerson notes three phasal differentiations, a heavy hornblende granite, a hornblende granitite, and a granite proper, all of which he attributes to the melting up of three various sorts of crystalline schists respectively (Bull. Geol. Soc. Am., I, 1890, p. 559). A similar affection of a porphyritic granite by a hornblendic country-rock is found in Chor Mountain, India (Geology of India, 2d ed., by Oldham; Strat. and Struc., p. 43); while quite recently Harker notes a good case of a relatively basic modification of granophyre at its junction with gabbro, and ascribes it mainly to an incorporation of re-fused gabbro (Q. J. Geol. Soc., 1895, p. 134).

it may be asked, why does the porphyritic granite not show more variations of mineral content? To this question we have no conclusive answer. It is possible that the rock which now fills the areas of the porphyritic granite was in general not at a temperature high enough to cause vigorous melting up of the walls, and that the great spaces in the earth-crust now filled by the granite were opened during the passage upward of earlier and hotter parts of the same magna. However this may be, the difficulty remains just as great for any theory of a metamorphic origin for the granite. It is impossible to believe that a rock with such continuity of like characters should have resulted from the alteration of the stratified or schistose rocks in the accompanying terranes of New Hampshire. Although the determinations of relative age among these terranes are as yet necessarily imperfect, we know that the porphyritic granite is in contact with rocks of many different horizons and of very variable composition. From this fact, it seems reasonable to conclude that the porphyritic granite is an exotic eruptive, finding its source of supply elsewhere than in any metamorphic center in immediate connection with the encircling schists. McMahon lays considerable stress on this idea in his argument for an eruptive origin of the Himalayan granites.[1] Lawson, in his study of the Laurentian gneisses, and Barlow, in a similar problem among the ancient rocks north of Lake Huron,[2] refer their "irruptive" masses to a fusion of the granitic floor on which the post-Laurentian rocks were laid. The New Hampshire rock is thus, in respect to its origin, more closely allied to the Himalayan granite than to the gneiss of the Canadian Laurentian.

Coarse veins cutting porphyritic granite.— McMahon and others describe plutonic eruptives intersected by dikes and veins of very similar material to that of which their hosts are composed. Besides the usual evidences of an eruptive origin for the Dalhousie gneissose granite of northern India, McMahon adds a criterion which is certainly without the weight of its associates,

[1] Geol. Mag., 1887, p. 216; Rec. Geol. Surv. India, XVIII, 1885, p. 106.

[2] Bull. Geol. Soc. Am., IV, 1893, p. 331.

but which has been recently used more than once. He states that "the granite contains veins similar to those caused by shrinkage on cooling in granites of admittedly eruptive origin."[1] Emerson makes the principle more definite. Speaking of the largest granitic intrusion in Massachusetts west of the Connecticut River, he says: "The great mass is cut everywhere by a very great number of dikes of a coarse muscovite-granite, which seem to represent later intrusions of the central portions of the mass into shrinkage cracks in the already cooled peripheral portions, and thus to represent more truly its original composition."[2] This seems to be the best interpretation of those coarse dikes cutting the porphyritic granite composed of large individuals of the same minerals that make up that rock. They occur everywhere, though there is a concentration of them along the boundaries. With them are often associated the pegmatite veins of variable mineralogical constitution of aqueo-igneous origin and apparently without direct connection with the underlying magma.[3] On Gun Mountain, on Bear Hill, on the road following the valley of Rixford brook, and in the eastern area near New Hampton Centre, dikelike bodies of the former kind transect the porphyritic granite. Such localities suggest that in this respect also the main granitic mass is eruptive.

The age of the porphyritic granite.—We have seen that the porphyritic granite intrusions were posterior to the stress-period during which the chief metamorphism of the New Hampshire rocks was brought about. The position of the axis of flexure determined largely the shape of the different important areas. Each one is batholitic in its nature. Since the eruptions ceased, no considerable deformation has occurred. In this, all the areas are alike, and from other facts, too, they were without much doubt essentially contemporaneous.

Now, the geologically highest fossiliferous zone within the

[1] Geol. Mag., 1887, p. 216.

[2] Bull. Geol. Soc. Am., 1890, p. 559. Cf. HARKER and MARR, Q. J. Geol. Soc., 1891, p. 284.

[3] Cf. BARLOW, Am. Geol., VI, 1890, p. 29.

mountain-built strata is the well-known one at Bernardston, Mass., some seven miles to the southwest of the Ashuelot area. The first studies of the organic forms enclosed in the limestones at this place referred them to the Helderberg or lower Devonian. More recent determinations now fix the age of the limestones as being at the Hamilton-Chemung stage of the Upper Devonian. They are folded up with quartzites and mica- and hornblende-schists which are intensely metamorphic. The careful field work of Professor Emerson and of the late Professor Dana has shown that these metamorphic rocks are a part of the same terrane which throughout this paper and the survey reports of the New Hampshire survey has been called the "Coös group." As early as 1873, Dana concluded that "the Bernardston, South Vernon, and Northfield beds being of Helderberg age, the Coös group, which is but the northern continuation of the same series, is, if correctly traced out, also Helderberg."[1] Professor C. H. Hitchcock adopted this view, although he disagreed with Dana as to the stratigraphic order of the rocks adjacent to the limestones.[2] Professor Emerson followed with the publication of his results after a painstaking lithological and structural study of the whole area. In this paper he most emphatically states his conviction and advances new proof that Dana's position was the correct one.[3] Two years later Dana reiterated his opinion,[4] and in his last and greatest work clearly shows that it persisted for the rest of his life.[5] Professor Emerson is inclined to place the faults and folds which dislocate the Bernardston rocks in Carboniferous or post-Carboniferous time. He attains this result by combining his observations at Bernardston with those in the more richly fossiliferous localities farther south, in the state of Massachusetts. Thus we may conclude that the porphyritic granite is probably a post-Carboniferous

[1] Am. Jour. Sci. (3), Vol. VI, 1873, p. 349.

[2] Am. Jour. Sci. (3), Vol. XIV, 1877, p. 380.

[3] Am. Jour. Sci. (3), Vol. XL, 1890, pp. 263 and 366; especially p. 366.

[4] *Ibid.* (3), Vol. XLIII, 1892, p. 456.

[5] Manual of Geology, pp. 310, 325.

intrusive and certainly younger than the upper Devonian at any rate.

Posterior to the schists, to the so-called protogines, and to other old eruptives on the one hand, the porphyritic granite is, of course, older than the aplitic and lamprophyric dikes which intersect it. It is also older than the Fitzwilliam granite, the hornblende granite stock of Mount Whiteface, the Franconia breccia,[1] and probably older than the complex stocks of the Waterville area. It is impossible with the facts now in hand to go further in fixing an epoch for these great intrusions. The porphyritic granite may even belong to the Tertiary.

SUMMARY.

Briefly stated, the chief conclusions which have been arrived at in the foregoing pages, are as follows :

1. The so-called "porphyritic gneiss" of New Hampshire is at least in the three most important areas, an eruptive porphyritic granite with a common tendency to develop planes of foliation.

It is not to be regarded as indigenous, that is, as the pure fused product of the surrounding formations — a deep-seated exotic origin must be posited for the granite. The evidences for an igneous instrusive origin include the composition and structure of the rock itself, the study of field-relations, the fluxional nature of the foliation, the uniformity of the rock in all its extent and the prevalence of secondary dikes and veins of injection apparently derived from the same magma. Besides these positive facts, there are also those embodied in what may be termed negative evidence. It includes all those observations that have been made in which the peculiarities of the region and of each intrusion will explain why some of the usual criteria of eruptive origins are not perfectly fulfilled. Chief among them is the fact of small certain and undoubted metamorphic effects at contacts — one which we have seen can be readily understood from the characters of the invaded rocks. Lastly, the contacts at first sight equivocal prove to be intrusive contacts on comparative

[1] Geol. of N. H., Vol. II, p. 257.

evidence. The existence of zones of passage between the porphyritic granite and the schists with which it comes in contact is a fairly common phenomenon in the case of stocks of plainly eruptive material. Such transitions then form no inherent objection to a similar origin in this instance.

2. The intrusions necessarily took place under great depth of strata. The latter were elevated by the last great period of White Mountain flexure and were practically holocrystalline products of the consequent metamorphism before the porphyritic granite was intruded. The subsequent disturbance of the greatest interest to us in this connection is that which caused the porphyritic granite to assume the parallel structure of flowage under differential stress analogous to that of the Himalayan and Alpine central granites. Since that time, the force operating on the terranes has been relatively slight. It has not sufficed to rub out completely, in any part, this initial structure of the porphyritic granite.

3. The molten rock entered the overlying schists in an irregular fashion but in general followed the regional line of strike of the White Mountain district.

4. Various considerations lead us to believe that the three areas of porphyritic granite described are virtually contemporaneous. They are, in every case, post-Devonian in age, — how much younger is unknown. Not being a basal formation, the terrane loses much of its value in an elaboration of the stratigraphic sequence and a reconstruction of the New Hampshire geological scale is necessary.

5. The porphyritic granite adds its testimony to the value of the opinion recently formulated among geologists that a highly important class of gneisses owes its parallel structure to fluxional movement. And it has the other general kind of interest in exemplifying the truth of Barrois' prophecy "que les terrains paléozoiques sont destinés à s'étendre de plus en plus sur les cartes géologiques aux depens des terrains primitifs."

REGINALD ALDWORTH DALY.

HARVARD UNIVERSITY.

SUPPLEMENTARY HYPOTHESIS RESPECTING THE ORIGIN OF THE LOESS OF THE MISSISSIPPI VALLEY.[1]

THE loess problem still remains obstinate. While it has yielded somewhat to progressive research, there is, I think, a nearly universal feeling of dissatisfaction with all theories thus far advanced. The eolian hypothesis appears to be the better supported so far as concerns the chief deposits of China and perhaps some of those of western America, while the aqueous hypothesis seems best supported so far as concerns the deposits of the Mississippi valley and western Europe. It is the judgment of some students that the ultimate solution will lie in the recognition of both hypotheses, but the means of discriminating between the two and of applying the criteria are as yet wanting. The present paper is intended to be a contribution in this direction. It is confined to the loess deposits of the Mississippi valley, but is probably applicable to the loess of western Europe.

The distribution of the loess in the Mississippi valley seems to be very significant in its peculiarities. These may be summed up in two great features.

1. The loess is distributed along the leading valleys. These embrace not only the great valleys, the Missouri and the Mississippi, but some of the subordinate valleys, as the Illinois, the Wabash, and others. The loess is found along the Missouri River from southern Dakota to its mouth; along the Mississippi River from Minnesota to southern Mississippi; along the Illinois and the Wabash from the points of their emergence from the territory of the later glacial sheets to their mouths. Along these valleys the loess is thickest, coarsest and most typical in the bluffs bordering the rivers and grades away into thinness, fineness and non-typical nature as the distance from the rivers

[1] Read before Section E, Am. Asso. Adv. Sci. Aug. 12, 1897.

increases. In some instances the loess mantle rises to the divide and connects with the similar deposit of an adjacent valley, but the law of progressive fineness and thinness still holds. This relationship is such as to create a very strong conviction that the deposit of the loess was in some vital way connected with the great streams of the region.

2. The second significant feature is the distribution of the loess along the border of the former ice-sheet at the stage now known as the Iowan. (Strictly speaking there was more than one stage of loess formation, but for convenience only the main stage will be here discussed.) The elaborate paper of McGee made us familiar some years ago with this relationship in eastern Iowa. The studies of Calvin and his colleagues, Bain, Beyer, and Norton, of the Iowa Survey, of Winchell and Upham of the Minnesota Survey, of Todd of the South Dakota Survey, and of Salisbury, Leverett, Udden, Buell, Hershey, and the writer of the United States Survey, have greatly extended the evidence of this relationship. It has recently been much advanced by the Iowa geologists and by Leverett and Hershey in northwestern Illinois. Next the border of the ice-sheet the loess is thick and typical, but graduates away with increasing distance from the ice border in a manner similar to the graduation away from the river valleys. On the border next the ice there are developed the formations designated by McGee paha, elongated domes of quasi-drumloidal contours which are mantled by loess. This superficial loess graduates downwards into loess of coarser and coarser texture until it often passes into a nucleus of sand. Below this there is often an embossment of till. These pahas seem to be ice border phenomena. Whatever their special mode of formation their distribution seems to connect them in some more or less direct genetic relationship with the ice.

It has been affirmed by several independent observers that the loess graduates into glacial clays and glacial till and this relationship further tends to confirm the association of the loess with glacial action.

It has been shown by the microscopical examinations of

Salisbury that the loess particles are composed in part of feldspars, amphiboles, pyroxenes and other common constituents of the glacial clays. These silicates are decomposable under prolonged weathering, and hence cannot well be supposed to come from residuary clays under the ordinary conditions of the Mississippi valley. The presence of the calcium and magnesium carbonates, independent of the presence of shells, points in the same direction. This inference is strengthened in a peculiar way by observations in the lower Mississippi valley. Above the Lafayette gravels and below the loess there is a stratum of silt which does not habitually contain the characteristic silicate particles of the loess. This stratum has been by most observers associated with the loess, but it is separated from it by a soil horizon as abundantly affirmed by the observations of Salisbury and the writer. On the other hand it graduates more or less freely into the Lafayette sands and gravels. The stratum is, as we interpret it, the last deposit of the Lafayette stage. It is a typical finishing deposit succeeding a fluvial sand and gravel. Now this has special significance in this relationship, in that it shows that in the stage closely preceding the loess deposit, the Mississippi did not lay down silts of the same constitution as the loess. The inference therefore is that the loess is not simply a fluvial silt brought down from the surface of the river basin, nor common wind drift borne into it, but that it had a special origin connected with glacial action which was competent to supply precisely the kind of silt of which the loess is made.

It is hard to resist the force of this argument from the constitution of the loess taken in connection with the two distributive relationships. Jointly they seem to force the conviction that the loess had its origin in some relationship to the ice of the Iowan stage and to the rivers that led away from the ice edge at that time.

But the hypothesis that the loess is simply an outwash of glacial grindings distributed along the river valleys by the glacio-fluvial waters is attended by grave difficulties. This remains true whether the deposition be supposed to have taken

place either in a strictly fluvial fashion, or in a fluvio-lacustrine fashion, or in a true lacustrine fashion, or in an arm of the sea. In the first place, the vertical distribution of the loess cannot easily be explained. The extreme vertical range is not far from a thousand feet. The range within a score of miles is frequently from 500 to 700 feet. The loess sometimes seems to the field observer to have a special fondness for summit heights. It sometimes mantles topography of a pronouncedly rolling type. It does not then appear to be a deposit which once had a level or even a smooth surface out of which the rolling surface has been eroded, but to be a mantle laid down upon a previously undulatory surface. Such a mantle might perchance be laid down from water, but I am not aware that we have any demonstrative deposition of the kind which closely simulates the mantling of the loess in some of the upland territory. To suppose that the Mississippi, Missouri, Illinois, Wabash and lower Ohio rivers were so swollen that they united over their divides and threw down a mantle of fine silt over the southern and western half of Iowa and the southern parts of Illinois, Indiana and Ohio, is a somewhat severe tax upon belief. It is difficult to imagine the conditions which should have maintained such a body of water. This has been so much discussed that I need not dwell upon it. But even if such a body be supposed, it is difficult to imagine how the deposition could have been precisely what we find in the case of the loess. It is futhermore difficult to account for the presence of the land shells which abound in it; for if this great flood had the ice-sheet for its northern border, it is extremely difficult to imagine how it could have been peopled so widely with the terrestrial mollusks.

The limit of the loess does not appear to be a strictly topographic one. It is difficult to bring its border into strict accord with a horizontal plain as required by the lacustrine and marine phases of the hypothesis, or even into a consistent gradient as required by the fluvial phase, without an arbitrary warping of the surface. The spread of the loess in the lower Mississippi valley is more extensive and reaches greater heights on the east

side than on the west side, so far as present knowledge goes. A similar fact seems to be true of the Missouri valley. I think this is generally true, but my observations are not sufficient to justify its unqualified affirmation as a generalization.

There are other difficulties attending the aqueous theory in its simple application, but I need not attempt an exhaustive recitial here as they have received emphasis in the long battle between the eolian and aqueous hypotheses. The foregoing will I trust suffice to show that there is abundant occasion to still cast about for a more satisfactory explanation of the loess puzzle.

The supplementary hypothesis herewith proposed attempts to divide the honors between the aqueous and eolian agencies. It recognizes the tremendous force of the arguments from the distribution and the constitution of the loess in favor of the glacio-fluvial hypothesis, and it adopts that hypothesis as the fundamental explanation of the origin of the Mississippian loess. It assumes the presence of the Iowan ice at the chief stage of loess deposition. It assumes a very low slope of the land and a consequent wide wandering of the glacial waters. It assumes the development of extensive flats over which the silts derived from glacial grinding were spread. It assumes that the glacial waters were subject to great fluctuations; 1° as the result of periods of warm weather in the melting season, and 2° as the result of warm rains, which not only added directly to the volume of water, but forced the rapid melting of the ice. Gilbert has acutely observed that there is no way in which the atmosphere can convey its heat energy to a glacier so effectually as through warm rains.

Let it be imagined, therefore, that the silty waters from the margin of the ice-fields wandered over broad flats and constantly built them up by their sediments, and that at periodical flood stages they extended themselves widely over the plains, while between the flood stages they withdrew to more limited courses.

The territory covered by the maximum extension of the waters would be the zone of accumulation of fluvial loess. It is

not necessary to suppose that the periodic extensions of the floods were destructive of the vegetation over all the flat region. In some portions not only could vegetation persist, but the land mollusks and other animals dependent upon the vegetation could find a temporary retreat from the flood on the taller vegetation that may have prevailed.

After each of the periodical retreats of the water there would be left extensive silt-covered tracts facily exposed to the sweepings of the wind and from these, when dried, dust could be derived in great quantities to be borne away over the adjoining lands and lodged in their vegetation. The material thus derived would be essentially identical with the glacio-fluvial deposition, and thus the hypothesis seeks to account for the glacial element in the constitution of the eolian portion of the loess. The presence of land mollusks in the upland eolian loess finds in this way a ready explanation, while their presence in the lowland loess mingled with aqueous mollusks finds an almost equally obvious elucidation ; for not only would the upland shells be washed into the lowlands, as we observe they are at the present time, but they would periodically invade the lowlands in the intervals between submergence and would be caught and buried there. Occasionally the shells of the lowland and aqueous mollusks would be borne to the uplands by organic agencies, and possibly in rare instances by the severest type of winds, and hence their occasional presence there is not remarkable.

To make this a good working hypothesis it would appear that there must be an accommodation between the breadth and fluctuations of the fluvial deposits and the extent and massiveness of the eolian deposits, for if we suppose the glacial floods to be confined within narrow channels, the sweeping ground of the winds would have been too scant to give origin to the great mantle of silt then attributable to them, for we must remember that in proportion as the river work is narrowed the wind work is expanded. It is obvious that the eolian factor will cut away its own ground if pushed too far.

There is little question that loess-like accumulations are now

taking place on the bluffs adjacent to the Mississippi and Missouri valleys. Observation seems to clearly indicate this. But such accumulations are relatively scant in amount and limited in extent, and it is difficult, if not impossible, to believe that the great loess mantle had its origin from the wind drift of flood plains no more extensive than those of today. It must be constantly borne in mind that the eolian deposits are measured, not by the quantity of silt borne by the winds and lodged on the surface, but by the *difference* between such lodgment and the erosion of the surface. Under most conditions with which we are familiar the erosion is more than a match for the dust accumulations. The conditions must then have been extraordinary which would give a dust deposition sufficient to supply erosion and still leave so large a residuum as the loess mantle implies. The unleached and relatively unweathered nature of the body of the loess is specially in point here. These considerations warn us of the theoretical danger of too greatly circumscribing the fluvial action.

On the other hand, if we attempt to extend the fluvial hypothesis too greatly we fail to leave sufficient feeding ground for the molluscan life and we encounter the topographical and physical difficulties which have been previously urged against the pure aqueous theory. A Janus-faced hypothesis is here offered in the hope that by a judicious reference of a part of the loess to one class of action and a part to the other, a joint explanation may be found to afford a true elucidation of the perplexing formation. At any rate, it has seemed worth while to propose the hypothesis for trial. It will doubtless be extremely difficult to find a line of demarkation between the two classes of deposits. Such attempts as have been made in this line justify this apprehension. This supplementary theory has been in mind for several years and was briefly suggested in my paper on the *Genetic Classification of the Pleistocene Deposits*, presented at the Fifth Session of the International Congress of Geologists at Washington in 1891.[1] An effort has been made

[1] Compte-Rendu of the Fifth Session of the International Congress of Geologists, Washington, 1891, p. 192.

by some of my colleagues and by myself to find criteria of discrimination between aqueous and eolian loess. While individual types of both deposits are not difficult to find, a criterion or a series of criteria of general applicability which shall distinguish the two and assign to each its appropriate part is yet wanting.

Richtofen in his classic work on China urged as the explanation of the great Chinese loess an eolian hypothesis supplemented by a fluvio-lacustrine hypothesis. He insisted that the original and chief loess deposits were formed by dust blown from the great arid plateaus and lodged on the more fertile plains of China, and that from these primary deposits the streams gathered and subsequently redeposited in fluvial or lacustrine form a subordinate portion, thus giving origin to a secondary loess formation. Going beyond that field he and his supporters have apparently tried to apply this secondary factor to the explanation of difficulties in the European and American loess, to which its application is more than doubtful. It is interesting, however, to note that the loess puzzle of China, even in the mind of its chief exponent, finds a full solution only in a combination of eolian and aqueous hypotheses. The present writer herein urges the trial of a similar combination of hypotheses, but reverses the order of the terms in their Mississippian application. The aqueous loess is made primitive and the eolian loess secondary. The Richtofen loess may be said to be first eolian and secondarily aqueous; the Mississippian loess, first aqueous, and secondarily eolian. The Richtofen loess in its ultimate origin is residuary. The Mississippian loess, in its ultimate origin, is glacial. The Richtofen mode of origin may be said to be eolio-fluvial, the mode herein advocated, fluvio-eolian, in which terms the order of the words indicates the order of derivation and each word signifies a variety of loess.

T. C. CHAMBERLIN.

CRYPTODISCUS, HALL.

In a recent paper in this Journal,[1] I figured and described some peculiar disk-like fossils from the Niagara limestone at Joliet, Ill., identifying them with Hall's genus *Cryptodiscus*, and interpreting them as the possible casts of the gastric cavities of Medusæ. At the time these descriptions were written a part of the material had been in my hands for two years or more. As the paper was going to press, too late for revision, additional material which suggested an entirely different interpretation, came into my hands from the collection of Mr. E. E. Teller, of Milwaukee, Wis. These new specimens are from the dolomitic Niagara limestone of Racine, Wis., and like the others are casts, the actual substance of the fossil being dissolved out. This new material shows that the disk-like bodies are not the complete fossils, but that they are attached to the summit of a tube composed of regularly arranged plates.

The disk portion of the fossil, to which Hall gave the name *Cryptodiscus*, was fully described in my former paper. It consists of an expanded disk with a variously lobed periphery, composed of four equal plates which occupy the position of the four quadrants of the disk. Figure 1, Plate A, and Fig. 6, Plate B represent the impressions of the lower and upper sides of a very complete specimen from Racine. It is similar to the specimen to which the name *Cryptodiscus digitatus* was given in my former paper, but differs from that species in the lobing of the periphery. If broken off at the bottoms of the lobes it would have the contour of *C. hydei*. The lower side of the disk with its central funnel-shaped depression with the central elevation is not different from those formerly described, but the upper side of the specimen is more nearly perfect than any of those. It is

[1] "On the Presence of Problematic Fossil Medusæ in the Niagara Limestone of Northern Illinois."—Jour. Geol., Vol. V, p. 744.

flat across the central portion with the exception of a small square fractured area in the exact center. This fractured portion corresponds to a similar fractured area at the summit of the central prominence of the lower side, and really represents a perforation through the disk in its perfect condition.

The impression of the upper side of the disk of another species is seen in Fig. 4, Plate A. The lobing of the periphery is different in this species, but its greatest peculiarity is in the presence of the impressions of four rather slender diverging spines, one on each quadrant, surrounding the fracture representing the central perforation of the disk.

In the limestone at Racine, associated with *Cryptodiscus*, the internal casts of some peculiar tubelike bodies have been found by Mr. Teller. Two views of the most perfect of these specimens are shown on Plate A, Fig. 3, and Plate B, Fig. 7. The tubes are composed of plates arranged in ranges of four each, and in the specimen illustrated the impressions of three such ranges are preserved. The top range consists of two longer plates and two shorter ones; the middle range consists of two plates below the shorter plates of the top range, which are placed higher than the two plates below the longer plates of the top. The lower ends of the basal range of plates are not preserved, but the summits are alternately higher and lower, to correspond with the plates of the middle range.

The specimen which forms the connecting link between the disk and the tube is illustrated on Plate A, Fig. 2. In this specimen the disk and the tube are both incomplete, but the relative position of the two is perfectly shown. The four quadrants of the disk are shown to be but the greatly expanded margins of the four plates in the top range of the tube, and the central elevation seen in the impressions of the lower side of the disk, is the summit of the internal cast of the tube.

When the relationship of the disk to the tube was recognized, the crinoidal character of *Cryptodiscus* could not be questioned; and a comparison of the arrangement of the plates in the tube with the arrangement of the plates in the dome of *Calli crinus*,

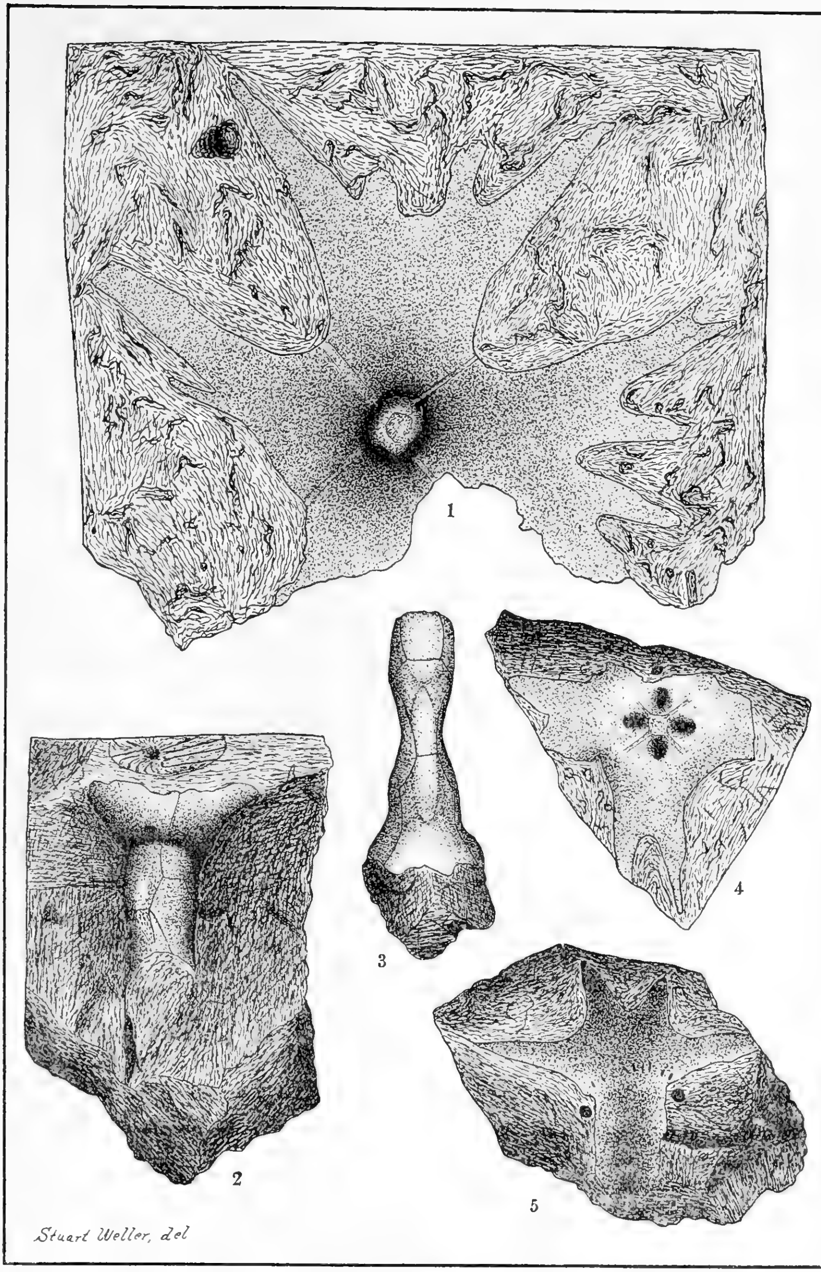
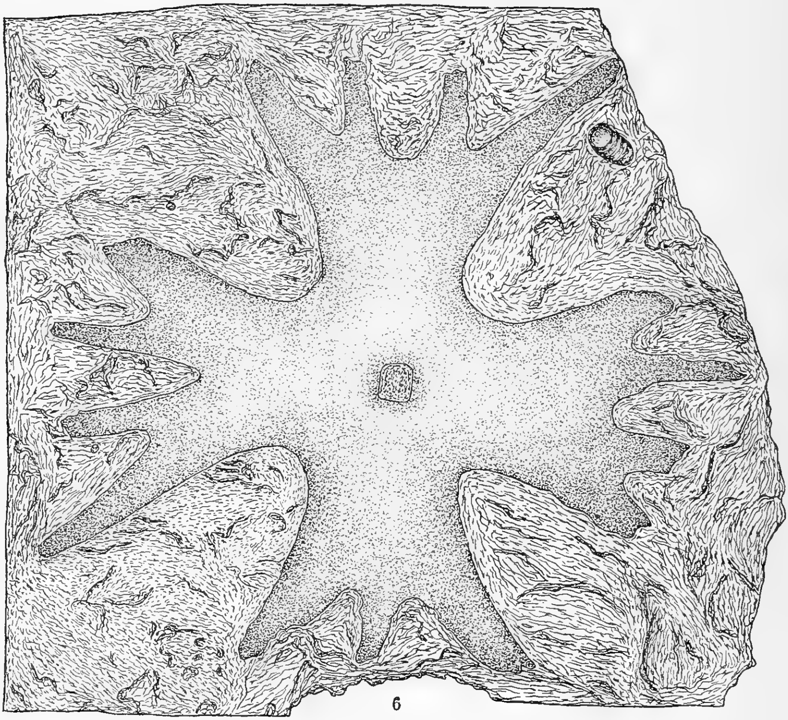


PLATE A



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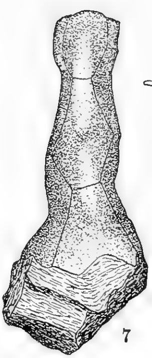

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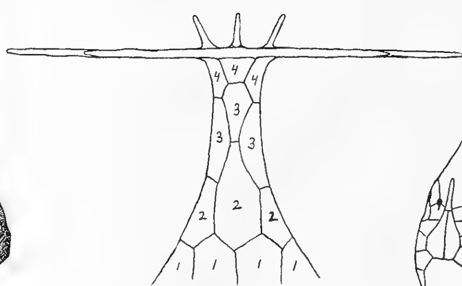

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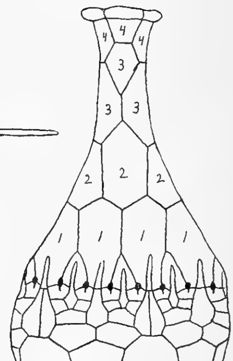

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Stuart Weller, del.

PLATE B

showed *Cryptodiscus* to be but a portion of the dome of members of that genus.

Figure 9, Plate B, is a diagram adapted from Wachsmuth and Springer, to show the arrangement of the plates in the calyx of *Callicrinus costatus* His., the type of the genus. The dome is composed of four ranges of plates, of which the first contains ten, and the second, third, and fourth ranges, four plates each.

Figure 8, Plate B, shows diagramatically the arrangement of the plates in the Racine specimen. The three ranges of plates present in these specimens correspond to the second, third, and fourth ranges in the dome of *C. costatus*. The plates in the Racine specimens differ from those of *C. costatus* in the third range; the two lower plates of this range are not in contact laterally, as in that species, but are separated by the downward extension of the two upper plates, which meet the truncated upper ends of the two corresponding plates of the second range. The most conspicuous difference between the Racine specimens and *C. costatus*, is in the greatly expanded margins of the plates of the fourth range, forming the disk to which the name *Cryptodiscus* has been applied.

Figure 5, Plate A, which shows the external impression of a portion of a disk attached to the tube, is introduced to show a peculiar ring-like canal which surrounds the tube just below its junction with the disk. This canal is open entirely around the tube so far as it is preserved, and a pliable wire inserted at one side passes around and out on the opposite side. On the impression itself, just above the angle between the disk and the tube, is a series of small slit-like openings which apparently connect with the ring canal. In the actual specimens, of course, these openings were represented by a solid ring around the tube, which was supported by a series of small bars connected with the basal portion of the under side of the disk. No explanation of these characters can be offered.

In their monograph, "The North American Crinoidea Camerata," Wachsmuth and Springer recognize from the dorsal cups alone, four species of *Callicrinus*—*C. beachleri* from St. Paul,

Ind., *C. acanthus* from Lockport, N. Y., *C. cornutus* from Racine, Wis., and Chicago, Ill., and *C. ramifer* from Tennessee. From the St. Paul beds in which *C. beachleri* occurs, Miller[1] has figured a specimen of *Cryptodiscus*. From the Racine beds, associated with *C. cornutus* the specimens illustrated in this paper were obtained. From Lockport, N. Y., and from Tennessee there is as yet no record of *Cryptodiscus*, but specimens may yet be found in these localities. The known localities for *Cryptodiscus* are Racine, Wis., Joliet, Ill., St. Paul, Ind., and Jones county, Ia., and in all these, with the exception of the last, the dorsal cups of *Callicrinus* are found associated with it.

The correlation of *Cryptodiscus* as a genus with *Callicrinus* seems complete, but material has not yet been found by means of which the species of *Cryptodiscus* may be correlated with the species of *Callicrinus* described from the dorsal cup.

The genus *Cryptodiscus*, founded by Hall, was never properly described, nor were the relationships of the fossils to which the name was applied, properly understood. D'Orbigny's name, *Callicrinus*, also has priority over Hall's, so it becomes necessary to drop *Cryptodiscus* entirely, and to refer all the specimens to *Callicrinus*. The different forms of disks doubtless represent distinct species of the genus, but there may be a difference of opinion as to whether species should be established upon the disk alone without a knowledge of the dorsal cup, and no names will be given to the Racine specimens for the present.

STUART WELLER.

THE UNIVERSITY OF CHICAGO.

[1] Eighteenth Rep. Dep. Geol. and Nat. Rec., Indiana, p. 260, Pl. I, Fig. 7.

A NOTE ON THE MIGRATION OF DIVIDES.[1]

San Clemente Island, one of a group lying off the southern coast of California, is a typical orogenic block,[2] formed by faulting in geologically recent times. Its drainage is still in its infancy, and is therefore very simple. A study of the topographical features of this isolated mass has led the writer to consider the effect on a previously established drainage system, of faulting with consequent migration of divides.

In the case of San Clemente, as the slope toward the line of faulting is by far the steeper, erosion on that side is much more rapid, and consequently the main watershed of the unmodified crust-block migrates away from that side toward the other. In this case then, the movement of the divide is from the line along which the elevation takes place—that is, from the line of faulting. This differs from an uplift along an axis, without faulting, in a topographically simple region of homogeneous rocks, as in the latter case the axis of uplift itself forms the ultimate divide, while in the former case the resulting divide is situated at some distance to one side of the line of faulting. Thus the effect on a simple drainage system already established will be different for the two kinds of crustal movements, and the law for the migration of divides as given by Campbell[3] must be modified in order to make it applicable to an uplift accompanied by pronounced faulting.

This may be illustrated as follows, assuming, as Campbell has done, the simplest possible conditions, in order to eliminate disturbing elements from the problem: In Figs. 1, 2 and 3, C represents the divide between the symmetrical drainage slopes

[1] Published by permission of the Director of the United States Geological Survey.

[2] Bull. Dept. Geol. Univ. Cal., Vol. I, No. 4, p. 129.

[3] Jour. Geol. Vol. IV, No. 5, July-August 1896, p. 580.

of the two stream profiles, C B A and C D E. If faulting occurs parallel to this divide, with a downthrow toward the left, it may occur on either side of C (leaving out of the question the possible occurrence of a fault at C itself). Suppose, first, that the fault is to the left of C, at B (Fig. 1), and that the

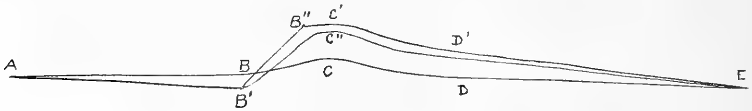

FIG. 1.

faulted portions have assumed the positions indicated by B″ C′ D′ E and A B′, A and E representing the limits of movement in either direction.[1] The part B C will have had its angle of slope decreased by elevation, and therefore the rate of erosion on this slope will be diminished. The angle of the slope C D E, however, will have been increased, and its rate of erosion will be correspondingly greater. The slope C′D′E, then, will be cut away more rapidly than the opposite slope, C′B″, and the divide, C′, will migrate toward B″, in accordance with the normal operation of the law. This condition, however, will last only a comparatively short time, for on account of the high angle of B B″ erosion on this slope will be very vigorous, and the point B″ will be rapidly carried back toward C′, till the two meet. When this stage is reached the edge of the faulted block will be represented by C″, and the profile, approximately, by B′C″E. Further erosion will tend to carry the crest C″ toward E, owing to the more rapid cutting on the steeper slope, B′ C″. The final result will be that the point C″ is carried to some point such as D′, the exact position of which depends on the relative attitude of the points which correspond to B′ and E, when erosion has reached this stage.

The second case (Fig. 2), when the faulting is between the

[1] These sections are diagrammatic, and do not attempt to give the exact relative positions of the two parts, as these positions depend on the circumstances obtaining at the time of faulting.

divide, C, and the point E, is similar to the last in the movement of the crest of the faulted block toward D, or away from the line of faulting. In the former case, however, the initial movement (for the fault-block) was toward the fault-line, while in this case that feature is eliminated, as the faulted portion D″ E excludes

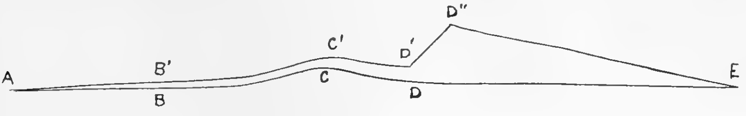

FIG. 2.

the original divide C. In this second case, this movement of the crest of the block D′ D″ E is thus away from the divide, C, also, and the final result of the uplift is the establishment of a divide for the crust-block, at some point betwen D′ and E, depending on the relative attitude of these two points.

If the faulting has been sufficient this resultant divide will form the main watershed for the region, the original divide, C being now of insignificant proportions. The faulting may, however, be such that the portion A B C D cannot be left out of account. If, as shown in Fig. 2, the final position of A B C D is more elevated than its original position, the slope C D will have been decreased, while A B C will have been slightly increased. As a consequence there will be a migration of C′ toward D′. If the faulting is sufficient in amount, the migrating crest will finally reach D′, and there will be no divide other than that of the faulted block, D′ D″ E. As the movement of the crest-line in this case is toward E for the parts on both sides of the fault-line, the resultant crest must be at some point between C′ and E, whether the amount of faulting be great or small.

If, on the other hand, the movement of A B C D is one of depression (Fig. 3), the result is more complicated, and the final position of the crest C′ will depend on the relative attitudes of the faulted portions A B′ C′ D′ and D′ D″ E. In other words, if the sum total of movement in the two parts produces elevation, the migration of the divide will be in the direction of E,

while if the resultant of the movement is a depression the divide will migrate toward A.

If the faulted block D′ D″ E were elevated from submarine depths to a position similar to that of San Clemente, the final

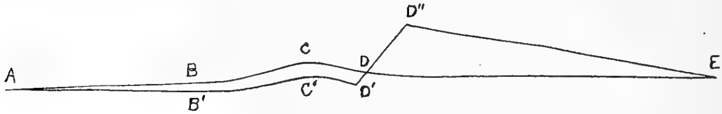

FIG. 3.

result of erosion would be a divide midway between the limiting waters on the two sides.

The results here arrived at must be true in all cases, whether the movements causing faulting are slow or rapid, continuous or intermittent in their action, and small or great in amount. Variation in these factors, however, will cause a variation in the rate of the migration, or in its extent. Other modifying factors are the relative positions of the divide and the line of faulting, and the dip of the fault-plane.

To sum up: Where simple crustal movements occur, causing faulting with resultant elevation, a migration of the stream divide will follow, in the direction of the line of faulting when the fault-scarp faces the divide, away from the line of faulting when it does not. Or, in other words, the migration is from the axis of faulting when the faulted block includes the divide, and toward the axis of faulting when it does not.

WM. SIDNEY TANGIER SMITH.

DISCOVERY OF MARINE JURASSIC ROCKS IN SOUTHWESTERN TEXAS.

SEVERAL announcements of marine Jurassic rocks in New Mexico and Texas have been made by authors, the earliest as also the latest by Mr. Jules Marcou; but the marine sediments hitherto called Jurassic in these states belong to the Comanche series. *Modiola jurafacies*, *Homomya jurafacies*, *Exogyra hilli*, and possibly one or two other members of the fauna of the latter series, which are more or less clearly analogous with fossils of the European Jurassic, should doubtless be regarded as survivals from a preceding age. Such survivals are only to be expected, and these therefore do not contradict the results arrived at by Professor R. T. Hill and Mr. F. H. Knowlton, who have shown that the lowest formation of the Comanche series presents a Wealden fauna and flora. The data of old-world stratigraphy seem to show that the Wealden formation is part of the Cretaceous system, or, more definitely, is the estuarine and arenaceous extension of lower Neocomian sediments that are elsewhere of purely marine origin and largely calcareous.

It is a principle recognized by many geologists that where the conditions afford only palæontological data for correlation and these data show a commingling of fossils of two successive systems, we should not suppose that the latest occurrence of fossils of the earlier system characterizes the highest rocks of that system, but should assume that *the first appearance of a fauna essentially characteristic of a later system, whether it be accompanied by survivals from an older fauna or not, marks the beginning of a new rock-system and age.* By this criterion Professor C. S. Prosser of the United States Geological Survey has recently drawn the line separating the Permian system from the Carboniferous in the Plains region; and in accordance with the same principle, if the prevalent European acceptation of the Cretaceous system

be adopted for America, the entire Comanche series belongs to the Cretaceous.

No true Jurassic of marine origin, therefore, has hitherto been recognized in the southern part of the United States.[1]

In 1893, when studying the Cretaceous fauna of Texas, as represented in the museum of the Geological Survey of that state, I was led to suspect the occurrence of Jurassic rocks in the vicinity of Malone, a flag-station of the Southern Pacific railway between El Paso and Sierra Blanca Junction. The evidence of such possible Jurassic formation was derived from the study of a small collection of Mesozoic fossils that had been obtained by Messrs. W. H. von Streeruwitz and Ralph Wyschetzki, according to the field-labels, "in hills about a mile northeast of Malone." The collection, though small, revealed a fauna quite different from any known in the North American Cretaceous, and one which, it was therefore surmised, might be pre-Comanche. All of the material that was deemed sufficient for study was treated of in the writer's "Contribution to the Invertebrate Palæontology of the Texas Cretaceous," in the Fourth Annual Report of the Texas State Geological Survey. It included six species, all apparently new to science, which were described under the following names: *Anatina tosta*, *Cucullæa transpecosensis*, *Cyprina* (*? Roudairia*) *streeruvitzii*, *Trigonia vyschetzkii*, *T. taffi*, and *Venus malonensis*. These fossils threw little light on the question of Jurassic or Cretaceous age of the rocks in which they occurred, as all of the genera were known to be common to both of these geological systems, and the two species of Trigonia were regarded as presenting features that allied them to both certain Jurassic and certain Cretaceous trigonias. The problem was therefore left unsolved.

Besides the Malone hills, the only locality where any fossil

[1] The Morrison Formation (Cross) of Colorado and Wyoming was traced along the front of the Rockies many years ago by Dr. F. V. Hayden at least as far south as Las Vegas, and its occurrence at the latter point has been recently confirmed by Professor Alpheus Hyatt. But this, though it has usually been called Jurassic, is now beginning to be regarded by some as probably lower Cretaceous (Wealden), and, whatever its age, is a fresh-water formation.

purporting to belong to the same fauna had been collected was Bluff mesa, upon which Mr. J. A. Taff of the Texas Survey had obtained part of the type-material of *Trigonia taffi*, the remainder being labeled as from the Malone locality. The rocks of Bluff mesa having been referred by Mr. Taff to the "Washita division"[1] (though the fossils he named from them were Glen Rose species) there was literary evidence that seemed to connect the Malone fossils with the Comanche series. Awaiting further light, they were therefore left among the fossils of that series. The "Washita" intended by Mr. Taff included both the true Washita, as originally established by Dr. B. F. Shumard under the name, Washita limestone, and the Denison formation of Professor Hill.

I did not, however, feel satisfied with this disposal of them, and I determined to reëxamine the matter at the earliest opportunity. This came in a journey made to Guaymas, Mexico, in the spring of 1895, by my friend, Mr. Robert W. Goodell, who, at my request, and assisted by his father, Mr. R. R. Goodell, very kindly made a side trip to the Sierra Blanca Mountains and the Malone hills to obtain further collections and data from those localities. From the Sierra Blanca Mountains, one of the localities of Comanche rocks nearest to the Malone hills, the Messrs. Goodell brought back many species of Mesozoic fossils, all of them apparently from Comanche rocks, most of them Washita forms, and many of them profusely abundant, but not one of them identical with fossils of the Malone hills. The Goodell collections from the Sierra Blanca Mountains and the Malone hills not only emphasized the distinctness of the fauna of the latter locality from that of the Comanche series, but they also settled the age of the Malone fauna. For, from the Malone hills they included, besides three of the species collected there by earlier explorers, several other forms, all of which seemed to be new to science,[2] and one of which was a

[1] Second Annual Report of the Geological Survey of Texas, pp. 719, et seq., and Plate XXVII.

[2] Since this was written, two of these forms have been found to be probably identical with two fossils that have been described from the Jurassic of Mexico. See footnote relating to *Pleuromya* and *Lucina*.

Trigonia of the section, *Undulatæ*, a type exclusively characteristic of Jurassic rocks. This beautifully ornamented shell is of medium or smaller than medium size in the genus, ovate, strongly inflated, and has the partly continuous and partly tuberculated ribs abruptly angulated. I have named it, after Mr. Robert W. Goodell, *Trigonia goodellii*. Moreover, a careful reëxamination of *Trigonia vyschetzkii*, made possible by the new material in the Goodell collection, indicated that it belonged to the *Clavellatæ* section of its genus, a section chiefly of Jurassic occurrence. As Trigonia is, among lamellibranchs, relatively important as a means of stratigraphic diagnosis, and as none of the Malone fossils agreed with species known in the lower Comanche, the evidence from the Goodell collection has led me to refer the Malone fauna and formation to the Jurassic system.

The vicinity of Malone was visited but once by the Messrs. Goodell (March 30, 1895), and then for only part of a day, their journey thither having been made from Sierra Blanca by wagon.

I am indebted to the kindness of Mr. Robert W. Goodell for the use of his field notes on the Sierra Blanca region, and particularly for those on the Malone hills, which include a section across the latter at a point considerably west of that at which Mr. R. R. Goodell collected the fossils and presenting different but apparently related conditions. His Malone hills notes are as follows:

A careful search of the western end of the line of hills one mile N. E. of Malone failed to reveal any fossils. The following is a section across the western end of this line of hills.

Bearing [magnetic] of line from station to beginning of section-line, N. 70° E.

Bearing [magnetic] of section-line, N. 20° E.; one-half mile from station. [Malone station.]

1) 340 feet heavily bedded limestone; no fossils; seams of calcite abundant; dip———; labeled M.

2) 30 feet coarse gypsum; dip 75° S. 40° W.; labeled N.

3) 10 feet laminated gypsum; dip 75° S. 40° to 50° W.; labeled O.

4) 50 feet red grits interspersed with seams of gypsum of various widths; dip 75° S. 40° to 50° W.; labeled P.

5) 110 feet coarse gypsum, same as N.

6) 450 feet heavily bedded limestone, with many seams of calcite which in places are several feet wide. That is, there are places several feet wide where there is more calcite than limestone. Dip hard to get, but at one place halfway across the bed it was 75° N. 40° E.; labeled Q.

General direction of hills nearly E. and W. The water has worn out a little draw in the gypsum beds between the limestone.

Several hundred yards west of where this section was made, at the extreme N. W. end of these hills, near the R. R., is an outcrop of soft sandstone. Parties have opened this up in one or two places, in search of fossils perhaps, but I could find no trace of any.

About a mile east of where I made this section, between the last two hills of this series, R. R. Goodell found an outcrop carrying fossils; a large clam, a Trigonia with rough nodular ridges, and two other bivalves. Outcrop 500 feet long, 150 feet wide; strike N. and S.; dip about 20°E.

Instead of four species of bivalves, however, the collection which the Messrs. Goodell brought back from this locality included seven, besides a fragment of an eighth and one of an ammonite. The bivalves included *Pholadomya tosta* (which the Goodell collection showed had been erroneously referred to the genus, *Anatina*); *Trigonia vyschetzkii;* the new Trigonia of the Jurassic section *Undulatæ, T. goodellii;* a subcircular, strongly compressed shell which is either a *Cyprimeria* or a *Lucina*, and to which I have given the MS. specific name *metrica*, from its being ornamented with concentric, sharply raised lines disposed at ample and remarkably regular intervals; a plain or gently and irregularly concentric-undulate, elongate *Pleuromya—P. malonensis* of my MS.,[1] showing in several examples the overlapping of the left hinge-margin by the right, characteristic of this genus; the *Venus malonensis*; an indeterminate ostreid (shown only in section, imbedded); and a fragment of another shell, possibly a *Trigonia* of the section, *Costatæ*. The *Pleuromya* bears more or less resemblance to *P. henseli* Hill, a Glen Rose species which the writer has collected at a number of localities

[1] Since this and the preceding species were studied, drawn, and named, I have recovered a mislaid copy of Castillo and Aguilera's "Fuana Fosil de la Sierra de Catorce" (Boletin de la Comision Geologica de Mexico, Num. 1), and it seems to me that there can be little doubt of their belonging respectively to the *Pleuromya inconstans* and *Lucina potosina* of those authors.

in north-central Texas and which is especially abundant in Hamilton county of that state. Specimens of both species, as usually preserved, vary somewhat in shape owing to mechanical distortion, and it is difficult to determine their precise natural form. Apparently, however, the Malone species differs from the *P. henseli* in having its posterior portion less tapering and a little recurved. The ammonite fragment did not show the suture; but the form and ribbing indicate a type common in the upper Jurassic.

As shown by the the rock adhering to fossils in the Goodell collection, the fossiliferous strata of the Malone hills consist in part of hard yellowish to brownish gray calcareous sandstone or arenaceous limestone. The sandy component is largely the débris of acidic eruptive rocks of undetermined varieties. But it seems probable that the massive, calcite-seamed limestone and the gypsum occurring in the more westerly part of the same hills and across which Mr. Robert W. Goodell's section was taken, are closely associated and should be referred to the same formation with them; and if so the similar gypsums and massive limestones of Malone Mountain, described by Mr. Taff as the *Malone formation* (which in several respects the Goodell section duplicates), is a prominent part of that formation. For the formation, therefore, provisionally regarded as embracing the fossiliferous sandstones and limestones, the gypsums, the massive calcite-seamed limestones, and any other rocks included among these, of the Malone Mountain and the hills north and east of Malone Station, Mr. Taff's name *Malone beds*, or Malone formation is appropriately retained. The Malone formation thus assumes wider limits, a different age-significance, and far greater importance than were assigned to it by Mr. Taff. Yet to him belongs the credit of having published the first section from it, and of having called attention to the fact that the Malone uplift is older than other orographic features of the Sierra Blanca district.

The Geological Map of Mexico, published by the late Director of the Geological Survey of Mexico, Señor Castillo, shows a

limited area of Jurassic rocks in northern Mexico, not far southwest of Saltillo. This is apparently the nearest known occurrence of marine Jurassic rocks to that here announced, being distant from Malone some 500 miles in a southeasterly direction. The discovery of Jurassic rocks in El Paso county, Texas, therefore, raises the interesting question whether other limited areas of Jurassic may not yet be discovered in intermediate territory.

This article in major part, including definite reference of the fossiliferous beds of the Malone hills to the Jurassic upon evidence derived from the Trigonias of the Goodell collection, was first written in the latter part of 1896. Its publication was postponed, — with some revision of the manuscript in the meantime, — in the hope that I might soon visit the formation in person and secure more abundant data. This I was unable to do till August last. Reaching the vicinity on the nineteenth of the month, I spent about three weeks exploring some of the localities accessible from Sierra Blanca station, devoting principal attention to the Malone fauna and formation. The large collection of fossils made from the latter, so far as yet studied, confirms the reference to the Jurassic. I at first intended to incorporate the results of this trip with those derived from the Texas Survey and Goodell collections and data ; but it has seemed best to publish deductions from the earlier data without the further delay involved in the study of this season's material, and to present the results of the latter study, when completed, in separate articles.

When this article was first written, I did not have access to the first number of the Boletin de la Comision Geologica de Mexico, containing Castillo and Aguilera's "Fauna Fosil de la Sierra de Catorce," my copy of it having been temporarily lost in the exigencies of a change of residence. The missing document has since come to light, and the independent reference which I have made of the Malone fauna to the Jurassic, is confirmed by it, *Pleuromya inconstans* and *Lucina potosina* being apparently common to the Malone and the Alamitos ("upper Jurassic") formations (as elsewhere indicated in footnotes), and

the ornamentation of the Malone ammonite fragment apparently agreeing with that of the Alamitos form, *Hoplites bifurcatus*.

In conclusion, I regret to have to record the recent decease of Mr. Robert W. Goodell, which occurred at his home in Houghton, Michigan, on the 23d of September last, and in his 28th year. I regard his early calling away, not only as a personal bereavement, but as a distinct loss to science as well; for, though an invalid, and unable to bear the confinement involved in the elaboration of his out of door observations, he was a young man of unusual intellectual ability and promise and an enthusiastic and careful observer. He had done considerable field work on the Laramie, Denver, and Fort Union formations in the area between Denver and Colorado Springs, and on several other matters of Colorado, Texas and Michigan geology; and, as appears in the present article, it is to his zeal as a scientific explorer that we owe the trip to Malone which, aided by his father's more robust physical strength, resulted in the means for the first satisfactory diagnosis of the age of the Malone hills fauna; and in an important advance in our knowledge of the distribution of North American Jurassic rocks.

F. W. Cragin.

Colorado Springs, Col.

ANDENDIORITE IN JAPAN.

In the northern fringe of the Kwanto plain, the environs of Tokyo, there is a series of volcanoes, including Asama, Haruna, Akaki, Niko, and Nasu, some of which are active, while the others are totally extinct. One of the oldest rocks erupted from these volcanoes is exposed at Usui Pass, in the form of propylite. The pass makes several trends along the steep, rocky slope of propylite mountains, and the railway of the Abt system passes through the rock by means of twenty-six tunnels. The propylite directly overlies the Miocene beds.

The propylite seems to have been derived from augite-andesite ; the normal variety has a homogeneous aspect, looking like a common andesite. The usual forms are altered. They are white or pale greenish, with scattered granular or sometimes cubical crystals of pyrite. Yellowish epidote grains and calcite crystals are also distinctly observed.

Midway between the telegraphic posts No. 367 and No. 368, on the same pass, I have seen, piercing through the above mentioned propylite, an interesting diorite dike, extending in an east and west direction. The eastern part of the dike is coarse-crystalline, while the other end is fine-granular or somewhat porphyritic.

The diorite, which is manifestly younger than the Miocene beds, is a hypidiomorphic aggregate of plagioclase and hornblende, with quartz, magnetite, iron pyrite, and remains of augite, sometimes mixed with hornblende. Epidote and chlorite, besides secondary pyrite, are also very common as secondary products. The plagioclase is distinguished with the naked eye as milky white grains, while the hornblende is greenish black, with a resinous luster on the newly cleaved surfaces. Iron pyrite and epidote grains are always found on the fresh surface of the rock, with their characteristic colors.

The plagioclase, which is the most important essential

ingredient in the rock, under the microscope is somewhat clear and fresh, exhibiting the extinction angle of labradorite. The albite type is the most common among twins, and the pericline type, also, is frequently found in the same individuals. Zonal structure, with different optical orientation, is often met with. Sometimes the core exhibits an eight-sided section, while the outline of the whole crystal is nearly rectangular. The crystal is often partly idiomorphic and partly allotriomorphic. It usually contains glass enclosures, which are seldom zonally arranged. Sometimes immovable gas bubbles are seen. The presence of liquid enclosures is very uncertain. The feldspar is generally fresh and clear. Decomposition begins at the cracks, where epidote grains are produced. In some cases they entirely replace the feldspar.

Next to the feldspar, the most abundant mineral is hornblende, either fibrous or compact, which fills up the interspaces between feldspar crystals. The characteristic cleavage along (110) is very distinct. The prevailing color is green, with the following pleochroism: $\mathfrak{a}$ = greenish brown, $\mathfrak{b}$ = brownish green, $\mathfrak{c}$ = green. The extinction angle is about 12°, but the decomposing individuals exhibit an undulatory extinction. Many of the hornblende crystals are derived from augite. The sections of the latter are brownish in color, with a greenish tinge, compact in texture, with their characteristic cleavage and an extinction angle of about 38°. Sometimes such a compact augite is converted into one with granular texture, each of the grains retaining the optical property of augite. The granular augite is converted into fibrous hornblende. These fibers are generally united in bundles, parallel to each other. The vertical and ortho-axes of the primary augite and of the secondary hornblende are nearly always in parallel position, sometimes forming a pseudomorph of hornblende after augite, which is distinctly seen in cross section. The green fibrous hornblende is further decomposed into epidote grains or chlorite. Occasionally all these stages of alteration may be seen in one section, surrounding each other in regular order.

Quartz which is surely primary is totally allotriomorphic, and fills up the interspaces between feldspar crystals. It is always fresh, contains glass enclosures, and sometimes well-shaped crystals of pyrite.

Magnetite is very common. An opaque ore, perhaps ilmenite, undergoes decomposition in such a manner as to leave more resisting lamellæ cutting each other at 60°. The pyrite contained in quartz is certainly of primary orgin.

Notwithstanding the holocrystalline structure of the rock, there are, occasionally, remnants of groundmass, which consist of microscopical grains of plagioclase, hornblende and iron ores. In a fine granular, porphyritic variety of the diorite, phenocrysts of feldspar are scattered in the aggregate of smaller lath-shaped feldspar individuals, which corresponds to the groundmass of the neovolcanic rocks. The above mentioned facts seem to show that the diorite is not a normal plutonic rock, but most probably a sheet or dike, which has solidified in the region of slight pressure.

Contact metamorphism.—In the neighborhood of the diorite, the propylite is so highly decomposed that traces of the contact metamorphism cannot be recognized. Although the Tertiary beds are never found in contact with the diorite dike, a Tertiary shale found about 330 feet to the north of the diorite is hardened like a hornstone and contains iron pyrite, which is not usual with the unaltered shale of the region. This change of shale seems to be due not to the action of the propylite lying between the diorite dike and the shale but to the diorite itself, which, in fact, has been taken out from a railway tunnel excavated close to the exposure of the shale. It seems probable that similar diorite dikes run through the Tertiary beds everywhere beneath the surface, because we frequently find hardened shale with a contact mineral, whose exact nature has not yet been ascertained.

Stelzner[1] describes a quartz-bearing mica-diorite of Argentine under the name of "Andendiorit" as a neovolcanic dike

[1] STELZNER, Geologie u. Palæontologie von Argentina, p. 213.

rock in the following words: "U. d. M. beobachtete man sehr deutlich Plagioklas, Quarz und braunen Glimmer; daneben scheinen auch noch kleinen Menze von Orthoklas und Hornblende vorhanden zu sein. Der Plagioklas ist sehr frisch, wasserhell, hier und da etwas rissig; er hat oft zonalen Bau beherbergt, wieder die oben bereits mehrfach beschriebenen Glasseinschlüsse von der Form negativer Krystälchen mit anhaftenden opaken Körnchen, ferner einzelne Flüssigkeitseinschlüsse, Dampfporen und farblose, sowie blassgrüne Mikrolithen. . . . . Die Hornblende tritt uns vereinzelt auf, und ist bereits durchgängig stark zersetzt und zerfasert."

The diorite at Usui Pass is also a Tertiary eruptive, and closely resembles Stelzner's andendiorite in the microscopical properties of the plagioclase, especially in the zonal structure and the glass enclosures with attached opaque granules, which are nearly always absent from the true plutonic diorite.

C. Iwasaki.

Kyoto, Japan.

STUDIES IN THE DRIFTLESS REGION OF WISCONSIN.[1]

THE superficial deposits of this region, aside from the interest which would naturally attach to any such deposit, possess a certain special interest due to the relation the region holds to the adjoining glaciated territory, and the presumption that they might furnish a record of certain subsidiary facts which from the nature of the case the glaciated region itself could not furnish.

The field as a whole is a most inviting one for study, presenting as it does considerable variety. But the purpose of this article is more especially to describe a particular deposit as seen in the vicinity of Trempealeau on the Mississippi River. As some knowledge of associated beds is necessary to a full understanding, I will briefly describe them in order beginning with:

The loess.—From the upper limits reached by the Champlain floods, all the smaller valleys, the lower hills, and, in a less degree, the higher hills are covered by a bed of clay, the average thickness of which may be between twenty and thirty feet, but it

[1] Early in 1894 Mr. G. H. Squier brought to the attention of the senior editor of this JOURNAL some observations which he had made on ridges of coarse gravel and bowlders in the vicinity of Tomah, Wis., which lies in the heart of the driftless area. It was his opinion that the formations constituted evidence of local glaciation. The débris was described as made up of chert and sandstone too coarse to be easily accounted for, in his opinion, by floods. It formed ridges on the slopes or side-plains of the valley and neither had the form of definite terraces nor of axial valley drift. No glacial striation either of the transported rock or of the rock *in situ* were observed, nor were glacial contours recognized in the configuration of the valley, nor distinctively in the ridges of débris. These deficiencies of evidence seemed less important however than the apparent absence of limestone débris. The deposit in question seemed to be made up wholly of sandstone, chert, and other residuary material. As limestone lay on the summit and formed the protecting crown of the highlands in which the valleys head, and as its habit of outcrop is such that it could readily yield massive blocks to glaciers occupying the heads of these valleys, and further, as limestone is habitually present in morainic débris formed in such situations.

varies greatly. Two measurements obtained not over ten rods apart, one on the crest of a hill, the other on its west slope, gave seventeen and thirty-two feet, respectively, with indications that at some intermediate point it may reach fifty feet. It is almost wholly free from stones and very homogeneous in texture, though the deeper parts are somewhat lighter in color and more friable, the result apparently of a large admixture of sand. Save in the valleys, it usually overlies the residual material derived from the disintegration of the underlying rocks, or near the foot of the hills, the talus, which being often nearly pure sand well shows the abruptness of the transition. In rare cases it rests directly on the rock.

while it is habitually absent from accumulations formed by weathering and by processes sequent upon weathering, the balance of evidence seemed to me adverse to the glacial hypothesis. At any rate, it seemed best to urge more prolonged and critical study before publication.

In February 1895 Mr. Squier presented similar data more fully worked out with reference to ridges of bowldery material accumulated about Trempealeau bluff on the Mississippi, in the northern part of the driftless area. The absence of limestone cannot be urged here with the same force as at Tomah, since it occurs in at least one locality. The absence of glacial scratches on the transported rocks as well as the valley sides, and the lack of specific morainic contours leave much to be desired here as at Tomah, but these deficiencies are not necessarily fatal to the glacial hypothesis. The conception of Mr. Squier, that the glaciers were formed by snowdrifts lodged in the valleys, and not by summit accumulations, is doubtless the true one if the glacial interpretation be true at all. Examples of such snowdrift valley glaciers occur in the extra-glacial belt in Greenland, and might reasonably enough be supposed to have occurred in the driftless area. But if these deposits are really due to local wind-drift glaciers decisive evidence of the fact should be forthcoming on a sufficiently prolonged and critical search. A coarse massive mixture of residuary material, however difficult of satisfactory explanation by other agencies, cannot safely be taken as in itself proof of glacial origin. It must be remembered that as a result of the excessive superficial thawing and freezing incident to glacier-border conditions, the facilities for landslides, bodily creeps, and similar modes of movement reached an extraordinary degree of development. I have seen in Montana a modern landslide that imitated a glacier almost perfectly in the deployment of its material. In Yellowstone Park, Mr. Hague showed me several years ago an almost perfect imitation of glacial deployment assumed by a talus mass of angular blocks of igneous rock. When such formations consist of mixtures of earthy and rocky material, their positive differentiation from glacial deposits may not be always successfully attained. So long as the constituent material is essentially residuary in origin, and there is an absence of any notable quantity of unweathered rock

Stratified beds.—In the valleys up to about one hundred feet above the river, the loess usually overlies stratified beds. The upper surface of the main body of the beds is not as high as given, but beds of similar character, of no great thickness, persist for a short but indefinite distance up the hillside. The thickest section I have seen shows about fifteen feet without exposing the base. In composition, sand forms by far the most abundant element, especially in the thickest places. Clay is present however, in some places interstratified with sand, and stones not exceeding a few pounds weight are plentifully included, all of local origin. The transition to the overlying loess is abrupt.

Peculiar stratum.—In one valley there is exposed a bed which, though of small size (four feet thick, and but a few rods in extent), possesses considerable interest from the fact that it contains pebbles of extra-local origin (granite, etc.). It intervenes between the stratified beds and the loess and is sharply distinguished from both. It is entirely unstratified, but presents a somewhat mottled appearance due to the imperfect mingling of the component elements, sand, clay, etc. It also contains stones of local origin not exceeding a few pounds weight. Its position both stratigraphically and topographically is such that it cannot be referred

wrested from its place as glaciers are accustomed to wrest a portion of their burden the suspicion of an origin by creep or slide or wash, or at least of some origin other than glacial, is invited.

But in view of the recent article by Mr. Frederick W. Sardeson in the December number of the *American Geologist*, in which the occurrence of glaciation in the driftless area is confidently announced on the basis of much more limited studies than those of Mr. Squier, and upon formations much more open to doubt than those near Tomah and Trempealeau, since they are described as wholly composed of sandstone, chert and earthy matter all referable to the residuary class, while the crowns of the ridges which closely overlook the valley on both sides are limestone, it is obvious that it might be unjust to Mr. Squier to urge longer search for the desired critical data before publication. It is even possible that this urgency in the past and the delay in the publication of his observations may not be free from the appearance of injustice. But fortunately the good judgment of geologists does not, in the better habit of today, rest much upon technical priority, but almost wholly upon the care and the completeness of the investigation. It has seemed only fair to Mr. Squier, however, to state thus fully the extent of his studies and the occasion of the delay in their published appearance.

T. C. Chamberlin.

to the time of the river gravels, but must be assigned to some earlier period.

Unstratified beds.—Overlaid by the stratified beds where they occur, otherwise by the loess, are certain deposits, which more especially form the subject of this article. They are confined to the valleys, where they have a much greater range than the stratified beds, reaching from two hundred feet or more above present river level to an unknown depth below. They consist characteristically of an aggregation of stones large and small together with the finer material forming the matrix. Although there is a considerable range of variation in the abundance and average size of the stones, in the relative abundance of the different kinds, and in the composition of the matrix, the general facies remains very constant. All the material so far as discovered is of local origin. Owing to a variety of circumstances it is difficult to give the thickness with anything like accuracy.

Details of structure will be best shown in the course of a description of the various exposures. The beds are for the most part entirely concealed from observation by the overlying deposits. It is only in the vicinity of the river where the latter have been wholly or partly removed, or where a deep ravine has penetrated to them that they can be studied.

Descriptive details.—The most extensive exposures occur about a mile and a half west of Trempealeau village. A sketch map of the locality is given in Fig. 1. At this point two old valleys converge so that they partly unite along the river front. The lower parts of these valleys (shown in outline on the map) have been filled up so that the drainage has been deflected, resulting in the formation of new gorges through the rock. Wherever these fillings are open to observation they are seen to consist of unstratified beds having the general characteristics above described. In the east valley loess occurs down to the bottom of the ravine above the filling, many feet below its crest.

The west valley offers rather the most favorable conditions for observation and section 2, Fig. 2, is taken along its axis. The filling takes the form of a well marked ridge extending across

the old valley. It is considerably broader and higher at the east end. At the west end it has been considerably encroached upon by the torrent course. At this end where it abuts against the

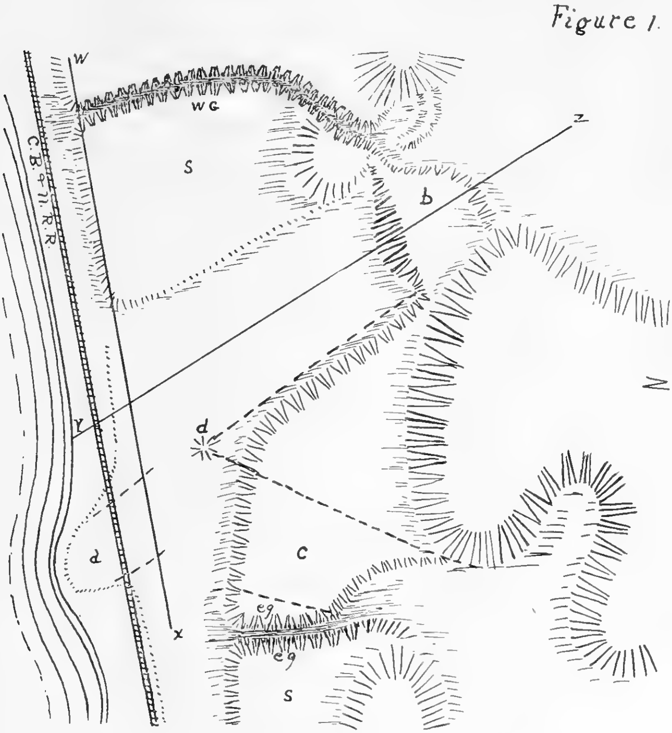

FIG. 1.—Sketch of map of vicinity of Trempealeau, Wis., described in text. Outlines of valleys in broken lines. *wg*, Rock gorge of west valley; *eg*, Rock gorge of east valley; *a*, Point composed of large rock masses; *b*, Transvesre ridge; *c*, Filling of east valley; *d*, Outlying low knob; *ss*, Sandstone plateaus; *wx*, *yz*, Lines of sections.

side of the valley, it meets a projecting spur from the hills, and through this spur the upper end of the rock gorge passes. Surface indications show that material similar to the ridge extends down the east side of the valley as far at least as the low knob *d*, Fig. 1, but its center along the line of section is occupied by nearly pure sand. On the west side gullies show that a bowlder bed

probably exists a few feet below the surface. Above the ridge loess begins and covers all the upper part of the valley. It is seen in the bottom of the ravine as it skirts the ridge, some twenty feet below its crest.

From the knob *d* a concealed ridge extends toward the river terminating in the prominent point *a*. The front of the point is lined with very large masses of rock reaching up to six or seven tons in weight. Excavations show that the entire ridge is composed of like material. The largest masses are usually sandstone. Chert is abundant and all the local rocks are represented. Sand covers the ridge to a depth of two to three feet and fills the valleys on either side to an unknown depth. The general direction of the ridge is shown by occasional protruding bowlders. As shown on the map, this ridge extends almost entirely across the course of the east valley. Yet its direction and other circumstances seem to indicate that it belongs structurally to both valleys.

About half a mile east of the two valleys just described occurs another, the largest in the Trempealeau bluffs. (It is the one in which the bed containing pebbles of extra local origin occurs.) At its mouth, on the east side, a bowlder bed is superimposed on the edge of a sandstone plateau (sec. 3, Fig. 2). In the size and character of the material, in structure, etc., it is a fairly representative example, although not as thick as most. No similar deposit is to be seen on the other side, although I should expect to find one under the sand. In the upper parts of this valley some interesting sections are furnished by washouts; owing, however, to their incompleteness they, for the most part, leave one in doubt as to the true nature of the structure displayed.

In one place the point of a hill has been washed away, showing that at that point the hill consists of a bowlder bed of characteristic type, the material being piled nearly as steeply as it will lie. The top and sides are covered with loess. The entire junction is visible, showing that the transition is as abrupt as possible (sec. 4). It cannot be seen whether it is part of a

ridge stretching across the valley or not. Less than a quarter of a mile east of this valley is another small one descending from the west side of the principal bluff. It first leaves the

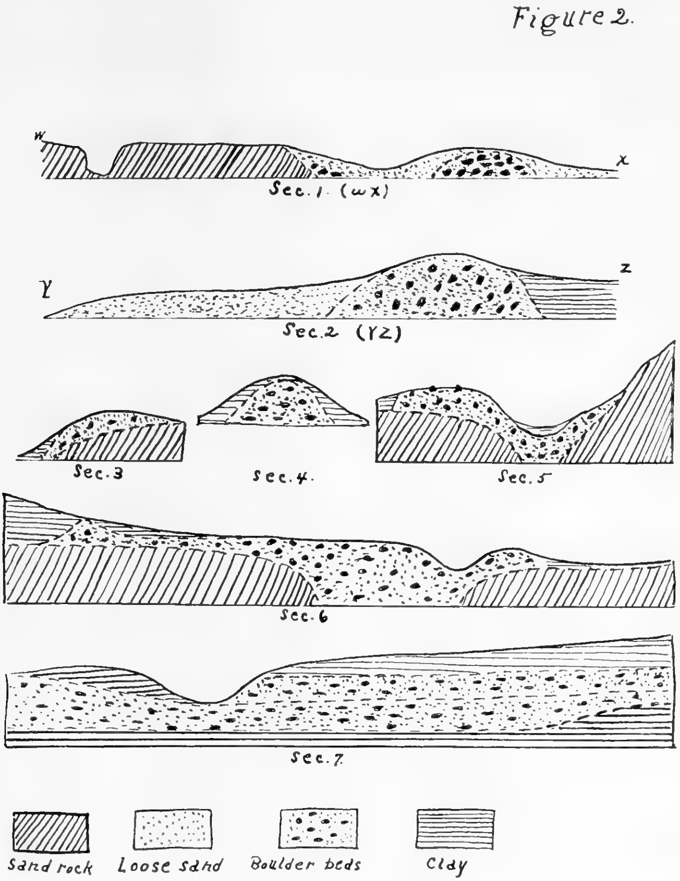

FIG. 2.— Section near Trempealeau, Wis. Scale about 240^{ft} to an inch, except in Sec. 7, which is about 65^{ft} to an inch. Datum, river level, except in Sec. 7.

confinement of the hills on the west side, at the same time changing from a nearly westerly to a southerly direction. Along this west side a large ridge of heavy bowlders is superimposed on a sandstone table. As the sandstone table falls away toward

the river the ridge also descends until it becomes merged with a bowlder bed which spreads out laterally to a moderate extent. Along the river front, this is cut into by the railroad excavation. The deposits are characterized throughout by the large average size of the material (equaling in this respect the ridge *a*, sec. 1) and by the abundance of limestone which forms masses at least as large as any. A smaller bowlder ridge can be seen on the east side after it leaves the hills.

Section 5 is made where the valley is still confined by the hill on the east.

Another valley, about the size and character of the last, descends from the eastern side of the same bluff and debouches into the center of Trempealeau village. In this case, also, a ridge extends across a sandstone table on one side, from the point where the valley leaves the hills. On the other side the valley skirts the foot of one of the main bluffs where the slope is gentle and the sides thickly covered with loess. A deep excavation has been made into this hillside for street construction. It shows the bowlder bed extending under the loess for a short distance, then suddenly rising into a ridge and as suddenly falling off. There appears to be a transverse ridge about where the line of section (sec. 6) runs, but it is not well defined. It is a difficult section to show.

In this valley the torrent course, after cutting through from forty to fifty feet of loess, has cut in places fifteen or twenty feet into the bowlder beds, thus giving opportunity for the study of the internal structure not elsewhere obtained. As, however, the section is not fresh it is only by much labor that it can be made available. It shows the bowlder beds alternating with beds of clay similar in appearance to the loess. Near the lower end of the ravine two bowlder beds occur above the bottom of the ravine and a hole seven feet deep in the bottom of the ravine struck the top of a third.

The thickness of a single bed ranges from about six to ten feet, varying considerably at different points. Roughly speaking the clay partings have about the same thickness as the bowl-

der beds. The general slope of the beds is only about one-third that of the ravine, so that they soon disappear from view, but further up the ravine and about thirty feet above the calculated horizon of the highest of the lower beds another one occurs about four feet thick, the parting being all clay. There appears to be another bed still further up.

In all the sections examined the extreme abruptness of the transition is noteworthy, the clay up to the very line of junction being absolutely free from stones.

Owing to the great labor of obtaining sections, and their small extent when obtained, it is impossible to answer many important questions regarding the form, extent, and relations of the beds.

Section 7 is fairly representative of the aspect of the beds in sections parallel to the valley. The relations shown at *p* were worked out carefully, and are of considerable interest. The upper bed, which terminates rather abruptly at that point, has a matrix composed mainly of sand, while in the lower bed the matrix is a compact clay. The transition from one to the other is quite abrupt.

Causes.—Although I should not like to express a final opinion as yet, I will, nevertheless, say that so far as the facts are known they seem to very strongly indicate one agent, while equally excluding others.

The agents capable of transporting material of the weight above described are few. Some of these may be dismissed with few words. Simple gravity, such as forms the talus of the hills, is excluded, since all the typical examples lie far outside its range of action. Wave action is also excluded. Neither can shore-ice offer any adequate explanation, although it can scarcely be doubted that it existed, and certain widely scattered bowlders, as well as certain sharply defined small pockets of local pebbles occasionally found embedded in the loess, may, with great probability, be assigned to this agent. Practically there are but two agents which need be considered. The one is torrential, the other, glacial action, in either case

operating during a period of subsidence, more or less interrupted by periods of partial reëlevation.

Torrential action.—Considered in the light of inherent probability, as well as in certain general aspects, this agent is doubtless the one we should select. The formations are strictly valley deposits. Torrents necessarily existed and must have produced characteristic deposits, and some of the beds at least might have been so formed. When, however, we take account of specific characteristics we find very grave difficulties, such as the transverse ridges. To account for these at all by torrential action it is necessary to regard them as ridges of erosion, the remains of a formation once occupying the entire upper part of the valley. The sequence of events which would thus be indicated is something as follows: (1) Subsidence, unstratified deposits; (2) Elevation, erosion; (3) Subsidence, stratified beds and loess, but no unstratified beds; (4) Reëlevation, erosion.

A study of local conditions furnishes several reasons why such a sequence of events must be regarded as violent and improbable. I will mention but one which alone seems to me to be fatal to it. As already stated, in the west valley above the ridge:

a. The loess covers everything high and low, even to the bottom of recent gullies, within a couple of rods of the upper end of the gorge, and a foot or two higher than its rock floor. Unless, therefore, we suppose that the gorge has received no appreciable deepening since the last elevation we must suppose that the early erosion extended deeper above the gorge than in the gorge itself. (How much deeper the loess extends, I do not know.)

b. The lateral ridges.—Not to occupy too much space I will refer to but one, the ridge marked *a* on the map. Assuming the two valleys to have been filled to the height of the ridge we should have to account for the removal of a very large amount of material, exceeding in the west valley the amount removed from its own gorge, yet its drainage area as compared with that

of the gorge is only as about 1 to 100. It would, morever, be necessary to account for the removal of material to a point considerably below present river level, which could only have been possible during a period of greater elevation, of which the gorge gives no indication.

c. There is excellent reason for believing that no torrents could have existed in these valleys capable of transporting the heavy bowlders found in the deposits. Of course I do not deny that torrents of sufficient power exist. I simply assert that in this as in all cases the question must be decided on the basis of local conditions. During the years that I have been familiar with the locality there have occurred several very heavy rains, and one of terrible severity, but never have I seen material transported reaching even the hundredth part of the weight of masses occurring in the deposits in question.

Moreover, a degree of subsidence sufficient to have allowed these deposits by such agency would have brought the valleys into the condition of broad flats with gentle slopes in which powerful torrential action would have been out of the question. We have also in the stratified beds, deposits formed under the conditions assumed, and having the characteristics we should expect.

Local glaciers.—That these, if we can suppose them to have existed, could have produced the specific effects above described, will not, I think, be questioned. I will, therefore, confine further remarks to facts having a negative bearing. Some of these have been anticipated in speaking of those favoring torrential agency. A further fact is that no undoubted case of glacial polishing or striation has yet been found, either on transported material or on the valley walls. The force of the objection is, however, practically destroyed by the fact that so far I have found only three exposures of rock so situated as to have fallen within the range of glacier action, while the transported material in sight, has been carried but a short distance and the greater share of that over beds of earlier deposit.

A more serious objection might be based on the general

insufficiency of the conditions for the production of glaciers. The present maximum height of Trempealeau bluff is but 548 feet above the river. It was, of course, less at that time in proportion to the amount of submergence.

But even were the elevation sufficient to allow of the formations of snow fields on the hilltops, and not elsewhere, still as most of the hills are little more than sharp ridges it would be quite impossible that the snow fields should have possessed volume sufficient to originate glaciers.

My own opinion is that under the influence of the wind the valleys themselves received a much larger annual accumulation of snow than would fall on the level, which, should it exceed in amount that which could be melted during the summer, would in time fill the valleys.

This suggests the further question whether were the valleys so filled there would be sufficient weight in the mass to give rise to glacial motion. A partial answer seems to be found in the small glaciers separated by Mt. Muir from the Sierra Nevada near the Yosemite Valley, which "have the structure and motion of true glaciers, but the largest is not more than a mile in length, and they vary in width from half a mile to a few feet." Some of those are therefore certainly smaller than the smallest indicated in this vicinity. Further information along this line would, however, be very desirable.

G. H. Squier.

Studies for Students.

THE METHOD OF MULTIPLE WORKING HYPOTHESES.[1]

There are two fundamental modes of study. The one is an attempt to follow by close imitation the processes of previous thinkers and to acquire the results of their investigations by memorizing. It is study of a merely secondary, imitative, or acquisitive nature. In the other mode the effort is to think independently, or at least individually. It is primary or creative study. The endeavor is to discover new truth or to make a new combination of truth or at least to develop by one's own effort an individualized assemblage of truth. The endeavor is to think for one's self, whether the thinking lies wholly in the fields of previous thought or not. It is not necessary to this mode of study that the subject-matter should be new. Old material may be reworked. But it is essential that the process of thought and its results be individual and independent, not the mere following of previous lines of thought ending in predetermined results. The demonstration of a problem in Euclid precisely as laid down is an illustration of the former; the demonstration of the same proposition by a method of one's own or in a manner distinctively individual is an illustration of the latter, both lying entirely within the realm of the known and old.

Creative study however finds its largest application in those subjects in which, while much is known, more remains to be learned. The geological field is preëminently full of such sub-

[1] A paper on this subject was read before the Society of Western Naturalists in 1892, and was published in a scientific periodical. Inquiries for the article have recently been such as to lead to the belief that a revision and republication are desirable. The article has been freely altered and abbreviated so as to limit it to aspects related to geological study.

jects, indeed it presents few of any other class. There is probably no field of thought which is not sufficiently rich in such subjects to give full play to investigative modes of study.

Three phases of mental procedure have been prominent in the history of intellectual evolution thus far. What additional phases may be in store for us in the evolutions of the future it may not be prudent to attempt to forecast. These three phases may be styled the method of the ruling theory, the method of the working hypothesis, and the method of multiple working hypotheses.

In the earlier days of intellectual development the sphere of knowledge was limited and could be brought much more nearly than now within the compass of a single individual. As a natural result those who then assumed to be wise men, or aspired to be thought so, felt the need of knowing, or at least seeming to know, all that was known, as a justification of their claims. So also as a natural counterpart there grew up an expectancy on the part of the multitude that the wise and the learned would explain whatever new thing presented itself. Thus pride and ambition on the one side and expectancy on the other joined hands in developing the putative all-wise man whose knowledge boxed the compass and whose acumen found an explanation for every new puzzle which presented itself. Although the pretended compassing of the entire horizon of knowledge has long since become an abandoned affectation, it has left its representatives in certain intellectual predilections. As in the earlier days, so still, it is a too frequent habit to hastily conjure up an explanation for every new phenomenon that presents itself. Interpretation leaves its proper place at the end of the intellectual procession and rushes to the forefront. Too often a theory is promptly born and evidence hunted up to fit in afterward. Laudable as the effort at explanation is in its proper place, it is an almost certain source of confusion and error when it runs before a serious inquiry into the phenomenon itself. A strenuous endeavor to find out precisely what the phenomenon really is should take the lead and crowd back the question, commend-

able at a later stage, "How came this so?" First the full facts, then the interpretation thereof, is the normal order.

The habit of precipitate explanation leads rapidly on to the birth of general theories.[1] When once an explanation or special theory has been offered for a given phenomenon, self-consistency prompts to the offering of the same explanation or theory for like phenomena when they present themselves and there is soon developed a general theory explanatory of a large class of phenomena similar to the original one. In support of the general theory there may not be any further evidence or investigation than was involved in the first hasty conclusion. But the repetition of its application to new phenomena, though of the same kind, leads the mind insidiously into the delusion that the theory has been strengthened by additional facts. A thousand applications of the supposed principle of levity to the explanation of ascending bodies brought no increase of evidence that it was the true theory of the phenomena, but it doubtless created the impression in the minds of ancient physical philosophers that it did, for so many additional facts seemed to harmonize with it.

For a time these hastily born theories are likely to be held in a tentative way with some measure of candor or at least some self-illusion of candor. With this tentative spirit and measurable candor, the mind satisfies its moral sense and deceives itself with the thought that it is proceeding cautiously and impartially toward the goal of ultimate truth. It fails to recognize that no amount of provisional holding of a theory, no amount of application of the theory, so long as the study lacks in incisiveness and exhaustiveness, justifies an ultimate conviction. It is not the slowness with which conclusions are arrived at that should give satisfaction to the moral sense, but the precision, the completeness and the impartiality of the investigation.

[1] I use the term theory here instead of hypothesis because the latter is associated with a better controlled and more circumspect habit of the mind. This restrained habit leads to the use of the less assertive term hypothesis, while the mind in the habit here sketched more often believes itself to have reached the higher ground of a theory and more often employs the term theory. Historically also I believe the word theory was the term commonly used at the time this method was predominant.

It is in this tentative stage that the affections enter with their blinding influence. Love was long since discerned to be blind and what is true in the personal realm is measurably true in the intellectual realm. Important as the intellectual affections are as stimuli and as rewards, they are nevertheless dangerous factors in research. All too often they put under strain the integrity of the intellectual processes. The moment one has offered an original explanation for a phenomenon which seems satisfactory, that moment affection for his intellectual child springs into existence, and as the explanation grows into a definite theory his parental affections cluster about his offspring and it grows more and more dear to him. While he persuades himself that he holds it still as tentative, it is none the less lovingly tentative and not impartially and indifferently tentative. So soon as this parental affection takes possession of the mind, there is apt to be a rapid passage to the unreserved adoption of the theory. There is then imminent danger of an unconscious selection and of a magnifying of phenomena that fall into harmony with the theory and support it and an unconscious neglect of phenomena that fail of coincidence. The mind lingers with pleasure upon the facts that fall happily into the embrace of the theory, and feels a natural coldness toward those that assume a refractory attitude. Instinctively there is a special searching-out of phenomena that support it, for the mind is led by its desires. There springs up also unwittingly a pressing of the theory to make it fit the facts and a pressing of the facts to make them fit the theory. When these biasing tendencies set in, the mind rapidly degenerates into the partiality of paternalism. The search for facts, the observation of phenomena and their interpretation are all dominated by affection for the favored theory until it appears to its author or its advocate to have been overwhelmingly established. The theory then rapidly rises to a position of control in the processes of the mind and observation, induction and interpretation are guided by it. From an unduly favored child it readily grows to be a master and leads its author whithersoever it will. The subsequent history of that mind in respect to that

theme is but the progressive dominance of a ruling idea. Briefly summed up, the evolution is this: a premature explanation passes first into a tentative theory, then into an adopted theory, and lastly into a ruling theory.

When this last stage has been reached, unless the theory happens perchance to be the true one, all hope of the best results is gone. To be sure truth may be brought forth by an investigator dominated by a false ruling idea. His very errors may indeed stimulate investigation on the part of others. But the condition is scarcely the less unfortunate.

As previously implied, the method of the ruling theory occupied a chief place during the infancy of investigation. It is an expression of a more or less infantile condition of the mind. I believe it is an accepted generalization that in the earlier stages of development the feelings and impulses are relatively stronger than in later stages.

Unfortunately the method did not wholly pass away with the infancy of investigation. It has lingered on, and reappears in not a few individual instances at the present time. It finds illustration in quarters where its dominance is quite unsuspected by those most concerned.

The defects of the method are obvious and its errors grave If one were to name the central psychological fault, it might be stated as the admission of intellectual affection to the place that should be dominated by impartial, intellectual rectitude alone.

So long as intellectual interest dealt chiefly with the intangible, so long it was possible for this habit of thought to survive and to maintain its dominance, because the phenomena themselves, being largely subjective, were plastic in the hands of the ruling idea; but so soon as investigation turned itself earnestly to an inquiry into natural phenomena whose manifestations are tangible, whose properties are inflexible, and whose laws are rigorous, the defects of the method became manifest and an effort at reformation ensued. The first great endeavor was repressive. The advocates of reform insisted that

theorizing should be restrained and the simple determination of facts should take its place. The effort was to make scientific study statistical instead of causal. Because theorizing in narrow lines had led to manifest evils theorizing was to be condemned. The reformation urged was not the proper control and utilization of theoretical effort but its suppression. We do not need to go backward more than a very few decades to find ourselves in the midst of this attempted reformation. Its weakness lay in its narrowness and its restrictiveness. There is no nobler aspiration of the human intellect than the desire to compass the causes of things. The disposition to find explanations and to develop theories is laudable in itself. It is only its ill-placed use and its abuse that are reprehensible. The vitality of study quickly disappears when the object sought is a mere collocation of unmeaning facts.

The inefficiency of this simply repressive reformation becoming apparent, improvement was sought in the method of the working hypothesis. This has been affirmed to be *the* scientific method. But it is rash to assume that any method is *the* method, at least that it is the ultimate method. The working hypothesis differs from the ruling theory in that it is used as a means of determining facts rather than as a proposition to be established. It has for its chief function the suggestion and guidance of lines of inquiry; the inquiry being made, not for the sake of the hypothesis, but for the sake of the facts and their elucidation. The hypothesis is a mode rather than an end. Under the ruling theory, the stimulus is directed to the finding of facts for the support of the theory. Under the working hypothesis, the facts are sought for the purpose of ultimate induction and demonstration, the hypothesis being but a means for the more ready development of facts and their relations.

It will be observed that the distinction is not such as to prevent a working hypothesis from gliding with the utmost ease into a ruling theory. Affection may as easily cling about a beloved intellectual child when named an hypothesis as if named a theory, and its establishment in the one guise may

become a ruling passion very much as in the other. The historical antecedents and the moral atmosphere associated with the working hypothesis lend some good influence however toward the preservation of its integrity.

Conscientiously followed, the method of the working hypothesis is an incalculable advance upon the method of the ruling theory; but it has some serious defects. One of these takes concrete form, as just noted, in the ease with which the hypothesis becomes a controlling idea. To avoid this grave danger, the method of multiple working hypotheses is urged. It differs from the simple working hypothesis in that it distributes the effort and divides the affections. It is thus in some measure protected against the radical defect of the two other methods. In developing the multiple hypotheses, the effort is to bring up into view every rational explanation of the phenomenon in hand and to develop every tenable hypothesis relative to its nature, cause or origin, and to give to all of these as impartially as possible a working form and a due place in the investigation. The investigator thus becomes the parent of a family of hypotheses; and by his parental relations to all is morally forbidden to fasten his affections unduly upon any one. In the very nature of the case, the chief danger that springs from affection is counteracted. Where some of the hypotheses have been already proposed and used, while others are the investigator's own creation. a natural difficulty arises, but the right use of the method requires the impartial adoption of all alike into the working family. The investigator thus at the outset puts himself in cordial sympathy and in parental relations (of adoption, if not of authorship,) with every hypothesis that is at all applicable to the case under investigation. Having thus neutralized so far as may be the partialities of his emotional nature, he proceeds with a certain natural and enforced erectness of mental attitude to the inquiry, knowing well that some of his intellectual children (by birth or adoption) must needs perish before maturity, but yet with the hope that several of them may survive the ordeal of crucial research, since it often proves in the end that several agencies were con-

joined in the production of the phenomena. Honors must often be divided between hypotheses. One of the superiorities of multiple hypotheses as a working mode lies just here. In following a single hypothesis the mind is biased by the presumptions of its method toward a single explanatory conception. But an adequate explanation often involves the coördination of several causes. This is especially true when the research deals with a class of complicated phenomena naturally associated, but not necessarily of the same origin and nature, as for example the Basement Complex or the Pleistocene drift. Several agencies may participate not only but their proportions and importance may vary from instance to instance in the same field. The true explanation is therefore necessarily complex, and the elements of the complex are constantly varying. Such distributive explanations of phenomena are especially contemplated and encouraged by the method of multiple hypotheses and constitute one of its chief merits. For many reasons we are prone to refer phenomena to a single cause. It naturally follows that when we find an effective agency present, we are predisposed to be satisfied therewith. We are thus easily led to stop short of full results, sometimes short of the chief factors. The factor we find may not even be the dominant one, much less the full complement of agencies engaged in the accomplishment of the total phenomena under inquiry. The mooted question of the origin of the Great Lake basins may serve as an illustration. Several hypotheses have been urged by as many different students of the problem as the cause of these great excavations. All of these have been pressed with great force and with an admirable array of facts. Up to a certain point we are compelled to go with each advocate. It is practically demonstrable that these basins were river valleys antecedent to the glacial incursion. It is equally demonstrable that there was a blocking up of outlets. We must conclude then that the present basins owe their origin in part to the preëxistence of river valleys and to the blocking up of their outlets by drift. That there is a temptation to rest here, the history of the question shows. But

on the other hand it is demonstrable that these basins were occupied by great lobes of ice and were important channels of glacial movement. The leeward drift shows much material derived from their bottoms. We cannot therefore refuse assent to the doctrine that the basins owe something to glacial excavation. Still again it has been urged that the earth's crust beneath these basins was flexed downward by the weight of the ice load and contracted by its low temperature and that the basins owe something to crustal deformation. This third cause tallies with certain features not readily explained by the others. And still it is doubtful whether all these combined constitute an adequate explanation of the phenomena. Certain it is, at least, that the measure of participation of each must be determined before a satisfactory elucidation can be reached. The full solution therefore involves not only the recognition of multiple participation but an estimate of the measure and mode of each participation. For this the simultaneous use of a full staff of working hypotheses is demanded. The method of the single working hypothesis or the predominant working hypothesis is incompetent.

In practice it is not always possible to give all hypotheses like places nor does the method contemplate precisely equable treatment. In forming specific plans for field, office or laboratory work it may often be necessary to follow the lines of inquiry suggested by some one hypothesis, rather than those of another. The favored hypothesis may derive some advantage therefrom or go to an earlier death as the case may be, but this is rather a matter of executive detail than of principle.

A special merit of the use of a full staff of hypotheses coördinately is that in the very nature of the case it invites thoroughness. The value of a working hypothesis lies largely in the significance it gives to phenomena which might otherwise be meaningless and in the new lines of inquiry which spring from the suggestions called forth by the significance thus disclosed. Facts that are trivial in themselves are brought forth into importance by the revelation of their bearings upon the hypothesis and the elucidation sought through the hypothesis. The phe-

nomenal influence which the Darwinian hypothesis has exerted upon the investigations of the past two decades is a monumental illustration. But while a single working hypothesis may lead investigation very effectively along a given line, it may in that very fact invite the neglect of other lines equally important. Very many biologists would doubtless be disposed today to cite the hypothesis of natural selection, extraordinary as its influence for good has been, as an illustration of this. While inquiry is thus promoted in certain quarters, the lack of balance and completeness gives unsymmetrical and imperfect results. But if on the contrary all rational hypotheses bearing on a subject are worked coördinately, thoroughness, equipoise, and symmetry are the presumptive results in the very nature of the case.

In the use of the multiple method, the reaction of one hypothesis upon another tends to amplify the recognized scope of each. Every hypothesis is quite sure to call forth into clear recognition new or neglected aspects of the phenomena in its own interests, but ofttimes these are found to be important contributions to the full deployment of other hypotheses. The eloquent expositions of "prophetic" characters at the hands of Agassiz were profoundly suggestive and helpful in the explication of "undifferentiated" types in the hand of the evolutionary theory.

So also the mutual conflicts of hypotheses whet the discriminative edge of each. The keenness of the analytic process advocates the closeness of differentiating criteria, and the sharpness of discrimination is promoted by the coördinate working of several competitive hypotheses.

Fertility in processes is also a natural sequence. Each hypothesis suggests its own criteria, its own means of proof, its own method of developing the truth; and if a group of hypotheses encompass the subject on all sides, the total outcome of means and of methods is full and rich.

The loyal pursuit of the method for a period of years leads to certain distinctive habits of mind which deserve more than the passing notice which alone can be given them here. As a

factor in education the disciplinary value of the method is one of prime importance. When faithfully followed for a sufficient time, it develops a mode of thought of its own kind which may be designated the habit of parallel thought, or of complex thought. It is contra-distinguished from the linear order of thought which is necessarily cultivated in language and mathematics because their modes are linear and successive. The procedure is complex and largely simultaneously complex. The mind appears to become possessed of the power of simultaneous vision from different points of view. The power of viewing phenomena analytically and synthetically at the same time appears to be gained. It is not altogether unlike the intellectual procedure in the study of a landscape. From every quarter of the broad area of the landscape there come into the mind myriads of lines of potential intelligence which are received and coördinated simultaneously producing a complex impression which is recorded and studied directly in its complexity. If the landscape is to be delineated in language it must be taken part by part in linear succession.

Over against the great value of this power of thinking in complexes there is an unavoidable disadvantage. No good thing is without its drawbacks. It is obvious upon studious consideration that a complex or parallel method of thought cannot be rendered into verbal expression directly and immediately as it takes place. We cannot put into words more than a single line of thought at the same time, and even in that the order of expression must be conformed to the idiosyncrasies of the language. Moreover the rate must be incalculably slower than the mental process. When the habit of complex or parallel thought is not highly developed there is usually a leading line of thought to which the others are subordinate. Following this leading line the difficulty of expression does not rise to serious proportions. But when the method of simultaneous mental action along different lines is so highly developed that the thoughts running in different channels are nearly equivalent, there is an obvious embarrassment in making a selection for

verbal expression and there arises a disinclination to make the attempt. Furthermore the impossibility of expressing the mental operation in words leads to their disuse in the silent processes of thought and hence words and thoughts lose that close association which they are accustomed to maintain with those whose silent as well as spoken thoughts predominantly run in linear verbal courses. There is therefore a certain predisposition on the part of the practitioner of this method to taciturnity. The remedy obviously lies in coördinate literary work.

An infelicity also seems to attend the use of the method with young students. It is far easier, and apparently in general more interesting, for those of limited training and maturity to accept a simple interpretation or a single theory and to give it wide application, than to recognize several concurrent factors and to evaluate these as the true elucidation often requires. Recalling again for illustration the problem of the Great Lake basins, it is more to the immature taste to be taught that these were scooped out by the mighty power of the great glaciers than to be urged to conceive of three or more great agencies working successively in part and simultaneously in part and to endeavor to estimate the fraction of the total results which was accomplished by each of these agencies. The complex and the quantitative do not fascinate the young student as they do the veteran investigator.

The studies of the geologist are peculiarly complex. It is rare that his problem is a simple unitary phenomenon explicable by a single simple cause. Even when it happens to be so in a given instance, or at a given stage of work, the subject is quite sure, if pursued broadly, to grade into some complication or undergo some transition. He must therefore ever be on the alert for mutations and for the insidious entrance of new factors. If therefore there are any advantages in any field in being armed with a full panoply of working hypotheses and in habitually employing them, it is doubtless the field of the geologist.

T. C. Chamberlin.

EDITORIAL.

THE laudable efforts of the Russian geologists to make the proceedings of the seventh session of the International Geological Congress contribute materially to the advancement of the science along the lines of unification and reformation of classifications and nomenclatures met with but partial success. The number of papers presented that bore directly on these problems was not large and their magnitude was inconsiderable. Nevertheless it will appear in the future that the effort was much more fruitful than seemed at the time to be the case. The results in connection with the classification and nomenclature of stratified formations were more immediate and satisfactory than those relating to the same problems in petrography. Messrs. Frech and Bittner prepared papers that led to the formulation by Messrs. Karpinsky and Tschernyschew of definite propositions for the establishment of principles upon which may be based rules for the creation and use of stratigraphical terms. These were discussed by the congress and agreed to in part. A new committee was appointed to consider the principles of chronological classification of sedimentary formations. The committee consists of active members and of consulting members. The former are: Messrs. Barrois, Capellini, Hughes, Renevier, Tietze, Tschernyschew, H. S. Williams, Zittel. Consulting members are: Choffat, Clark, Cortazar, Davy, Dawson, Déperet, Frech, Griesbach, Karpinsky, Kayser, de Lapparent, Martin, Mayer-Eymar, Nathorst, Nikitin, Stefanescu, De-Stefani, Taramelli, Uhlig, Van der Broeck, Walcott, Woodward.

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The results in connection with the problem of the reformation of petrographic nomenclature were most disappointing to the

Russian geologists, partly by reason of the fewness of the papers contributed and partly because of the resolution passed by the petrographers present that the time had not arrived for the determination of general principles for the classification and nomenclature of rocks. This, together with the absence of any report from the committee appointed at the sixth session of the congress prevented a discussion of principles and appeared to be a direct reproof of the geologists who had suggested the discussion. It should not be so considered. It was in fact an indication of the wide divergence of opinion on the subject of classification and nomenclature among petrologists and of the consciousness of the rapid changes that are taking place in our knowledge of the elements involved, which would render hasty deliberation fruitless. But there is no question that had a report been presented by the committee it would have elicited a most vigorous discussion. It is to be remarked also that an effort on the part of the petrologists to replace the former committee by a more active one was voted down by the help of those geologists who appeared most anxious to have the problem advanced. The undertaking is of such a serious nature that few cared to offer new suggestions without very careful consideration. Nevertheless the agitation will undoubtedly prove beneficial, and as great advances could be recognized to have taken place since the meeting of the sixth session at Zürich, still greater ones may be expected by the time of the Paris meeting, when it is hoped that the committee will present a report which may not only form the basis for discussion but a foundation for permanent reforms. J. P. I.

Reviews.

The Glacial Lake Agassiz. By Warren Upham. Monograph of the United States Geological Survey, Washington, D. C., 1895.

This *opus magnum* of one of our most active and worthy glacialists has fallen between the two horns of a dilemma common enough in the experience of the busy editor who hesitates between the hasty sketch which alone time permits him to prepare and the careful review which he knows he ought to prepare in due respect for the merits of the work. The choice of the latter which best suits the stress of the hour too often proves but a renewal of the dilemma with added intensity when he next recurs to the subject, and so the struggle goes on until the alternative narrows to an inadequate notice or an unworthy negligence of a work of merit.

This monograph of more than 650 pages, amply illustrated by maps and diagrams, represents several years of very industrious study of the surficial phenomena of the basin of the Red River of the north and adjacent territory, begun under the auspices of the Minnesota Survey and finished under those of the United States Survey with the coöperation of the Canadian Survey.

The treatment is systematic and detailed. Beginning with a general introduction it passes to the topography of the basin which is minutely described, after which the underlying formations embracing the Archæan, the two Silurians, and the Cretaceous, are discussed at some length. The glacial period and its drift deposits are treated with still more fullness because of their immediate relations to the history of Lake Aggasiz. This is introduced by a review of the glacial period in North America, and a comprehensive sketch of the continental ice-sheet which is illustrated by an excellent map showing not only the general distribution of North American Pleistocene glaciation as known at the time of its preparation, but also the directions of movement in various parts of the great area. Greenland

and the Archipelago north of the continent are included. The Laurentide and Cordilleran ice-sheets are differentiated and the debatable belt between them indicated. The Keewatin ice-sheet which has since been differentiated from the Laurentide glacier in part at least by Tyrrell is, of course, not separately represented. The recession of the ice-sheet and the courses of the ice movement in the immediate vicinity of Lake Agassiz are very fully set forth, as well as the drift deposits of the region. The succession of terminal moraines is amply delineated by text and maps. The moraines from the seventh or Dovre to the eleventh or Mesabi are regarded as contemporaneous with Lake Agassiz.

With this very ample but needful introduction the history of Lake Agassiz is delineated. A distinction is drawn between the Great Basin lakes, Bonneville, Lahontan, and others, and true glacial lakes of the Agassiz type. The indubitable evidences of the existence of the lake in a well-cut outlet, eroded cliffs, beaches, deltas, and lacustrine deposits, are set forth in general terms at the outset and taken up in much detail afterwards.

The contemporaneity of the great ice-sheet and the dependence of the lake upon the ice mass for its northern barrier is a central point of interest in the monograph. The changes in the history of the lake are made dependent upon the shifting position of this ice barrier, upon the erosion of the outlet, and upon progressive changes in the earth's surface. An attempt is made to measure the duration of Lake Agassiz by means of its beaches, its moraines, and correlated phenomena, with the result that the period is believed to have been short and the formation of the moraines very rapid. Some alternative interpretations by Chamberlin, under whose direction the work was prosecuted, are introduced at this point at the request of the author, the chief purport of which is to assign a series of rising as well as falling stages to the shores of Lake Agassiz and to thereby make the moraines antedate the highest beach and to leave the time occupied in their formation undetermined.

The beaches are divided into two classes, the one set being those connected with the southern outlet at Lake Traverse and the other set those connected with some undetermined outlet to the northward. Five distinct stages, represented by as many beaches or groups of beaches, belong to the first set and four to the second. One of the most important features of the monograph is the accurate determina-

tion of very notable changes in the level of these beaches. A former relative rise of the surface to the northeast is not only amply demonstrated, but a progressive fall of the surface at the north at later stages until it reached its present attitude is fully made out. The movement appears to have been steadily progressive and systematic. The possible causes of these changes of levels are discussed, embracing gravitation toward the ice-sheet which, while measurably effective, is found quantitatively insufficient, changes in the temperature of the earth's crust which is also regarded as insufficient, and epeirogenic movements apparently dependent in part upon glaciation, which is regarded as the essential agency. In this connection the author extends his discussion widely, treating of the preglacial elevation of North America, as shown by fiords and submarine valleys and of the late glacial or Champlain submergence shown by fossiliferous marine beds overlying glacial deposits, and from these he endeavors to deduce the Pleistocene oscillations embracing those which were independent of glaciation as well as those dependent upon it. He maintains his well-known views regarding the dependence of glaciation essentially upon epeirogenic movements.

The monograph closes with chapters on the artesian and common wells of the Red River valley and the agricultural and mineral resources of the area of Lake Agassiz. There are added appendices giving the courses of glacial striæ and notes on aboriginal earth works within or near the area of the lake. The whole material is worked out with care and great detail and constitutes a very important contribution to Pleistocene history in both its glacial and its lacustrine aspects. T. C. C.

Catalogue of the Tertiary Mollusca in the Department of Geology, British Museum (Natural History). Part I. The Australasian Tertiary Mollusca. By George F. Harris, F.G.S. 407 pp., 8 pls. London, 1897.

The British Museum, which has in process of publication catalogues of its great collections, has lately started a new series upon the Tertiary Mollusca, under the editorship of Professor Harris. The first volume dealing with the Australasian forms has just made its appearance. The acquisition by the Museum at different times since

1860 of large numbers of Teritary mollusca from Australia and New Zealand, has made it possible for Professor Harris to present a very exhaustive review of the subject, the Gasteropoda particularly being described in great detail. The fine state of preservation of the specimens has led the author to consider the several forms both from an ontogenetic and phylogenetic standpoint, and as so little work of this character has been done on the Gasteropoda, hitherto, it must prove of fundamental importance in the systematic classification of this class of the mollusca.

The book contains a complete synonomy of all the forms catalogued, together with a description of such new material as the Museum possesses. The admirable figures which accompany the volume show in great detail the protoconchs of many of the Gasteropod types.

This report presents the first thoroughly systematic treatment of the Tertiary molluscan faunas of Australasia and will be of great service to the student of Tertiary mollusca in other portions of the world. Volume I will be succeeded by others in which the large Tertiary collections of the British Museum from other lands will be minutely described. There is no man better able to undertake this task than Professor Harris, as he is intimately acquainted with the Tertiary in many portions of the world, and probably has a more comprehensive knowledge of the Tertiary of central and western Europe than any one living. He has published an important memoir on the Eocene geology and palæontology of the Paris Basin, besides making contributions to the Tertiary of England.

The future publications of this series will be awaited with much interest by all students of Tertiary palæontology.

Wm. B. Clark.

Transactions of the American Institute of Mining Engineers, Vol. XXVI. February 1896, to October 1896 inclusive. Published by the Institute, New York City, 1897.

This number of the *Transactions* presents a goodly list of papers of especial interest to geologists. Of these we may mention the following :

The Ore Deposits of the Australian Broken Hill Consols Mine, Broken Hill, New South Wales. By George Smith, pp. 69-78. This

is an interesting discussion on the concentration of dyscrasite and antimonial silver chloride where the lode is cut by cross veins or "*indicators*." The author finds it necessary to invoke the aid of the electro-magnetic currents of the earth's crust acting along the cross veins to account for this particular form of deposition.

Copper Ores in the Permian of Texas. By E. J. SCHMITZ, JR., pp. 97-108 (discussion p. 1051). The copper ores of the Texas Permian occur as pseudomorphs of wood or as nodules or copper-bearing shale, slate or clay, and was deposited under much the same conditions as the "*Hupperschiefer*" in the German Permian, the chief difference being that the American ore is in the main a carbonate or silicate, while the German is a sulphide.

Vein Walls. By T. A. RICKARD, pp. 193-241 (discussion p. 1153). A valuable dissertation upon the relation of ore deposition to the composition and structure of the inclosing strata.

Sketch of a Portion of the Gunnison Gold Belt, Including the Vulcan and Mammoth Chimney Mines. By ARTHUR LAKES, pp 440-448.

Gold in Granite and Plutonic Rocks. By WILLIAM P. BLAKE, pp. 290-298. A summary of a number instances of the occurrence of gold as a primary constituent of granite and plutonic rocks.

Faulting and Accompanying Features Observed in Glacial Gravel and Sand in Southern Michigan. By CARL HENRICH, pp. 460-464 (discussion p. 1102). The faulting occurs in stratified gravel. The fault planes are from seven to twelve feet apart, and none have a throw of less than seven inches. Along these fault planes nodules have been formed by *ascending* currents of water. The explanation offered is that lateral pressure was caused by two glaciers converging along Silver Creek and Goose Greek valleys.

Further Notes on the Alabama and Georgia Gold-Fields. By WILLIAM H. BREWER, pp. 464-472.

The Ore-Shoots of Cripple Creek, Colorado. By EDWARD SKEWES, pp. 553–579. A detailed description of the ore-shoots of a portion of the Cripple Creek district, and their relations to the vein fissures.

Traces of Organic Remains from the Huronian (?) *Series at the Iron Mountain, Michigan*, etc. By W. S. GREESLEY, pp. 527-534. An account of the author's discovery of certain markings on the iron ore

upon the docks at Erie, Pa. which he indentifies as fossil remains. Three plates follow the article.

The Phosphate Deposits of Arkansas. By JOHN C. BRANNER, pp. 580-598. The phosphate deposits are reported in or associated with a narrow zone either of greenish or black shale, or a sandstone deposited between recognized Lower Silurian and Carboniferous strata. This interval represents the slow accumulation of organic matter in a comparatively deep sea. Phosphate nodules have also been found in some of the Cretaceous beds of the region.

Magnetic Observation in Geological Mapping. By HENRY LLOYD SMITH, pp. 640-709. The principles of plotting magnetic observation and applications to geological mapping, etc.

Some Mines of Rosita and Silver Cliff, Colorado. By S. F. EMMONS, pp. 773-822. The ore of the Bassic mine was deposited by fumoralic action as a phase of the dying activity of the volcano when H_2S and S_2O were the prevailing gases. The Bull-Domingo mine ores were deposited from aqueous solutions coming from a region of igneous eruptions close at hand.

Discussing the composition of descending surface waters and ascending deep waters Mr. Emmons concludes, in opposition to the prevalent belief, that decreasing temperature and pressure are not the principal determining causes of the precipitation of vein minerals from ascending solutions. Also that all the metallic minerals of the plateau were formed under the same conditions and during the same general phase of ore deposition, and their irregular dissemination is due to physical rather than to chemical causes.

He states also that "the heavy metals have probably been brought up from the interior of the earth within the magmas of igneous rocks, and that by some process of differentiation not yet completely understood either previous to, or during the process of cooling and consolidation, they have been concentrated within certain bodies or parts of bodies of eruptive rocks ; and, further, that ore bodies as found at the present day are the result of a concentration (perhaps many times repeated) of the materials thus brought up, which are in all probability very finely disseminated through the present rock masses or combined in minute amounts in the more common basic minerals. This seems a more rational hypothesis, and one more in accordance with modern scientific practice, than to content oneself with assuming simply that

the ascending waters came charged with metallic minerals from the bathysphere, meaning thereby a region in the interior of the earth which is richer in heavy metals than any part of the earth's crust that comes under our observation ; for this simple assumption affords no explanation why metallic minerals are concentrated in one part of the earth's crust and not in another, and it supposes a free flow of waters at greater depths than in our present state of knowledge of terrestrial physics it is considered possible that channels which would admit of a flow of water through them would remain open.

"Furthermore, if the vein-materials are found to form a constituent part, even in minute traces, of comparatively fresh and unaltered country-rocks in a given ore-bearing region, and at such distances from any water-channels as to render it improbable that these materials could have been brought in through these channels, it is reasonable to assume that these or similar rocks have been permeated by the waters from which the known ore deposits were precipitated, and that from them they derived their contained vein-materials. . . . . It seems probable that not only the recent eruptives, but the older granites through which the ascending solutions must have passed, contain enough of the precious metals, and, it may be assumed also, of the other vein-materials to furnish, in the long time that is accorded to the accomplishment of most geological phenomena, sufficient material of the formation of existing ore-bodies. The analysis of the vadose waters in the Geyser mine has demonstrated the capability possessed by even cold surface waters of taking up such materials in their passage through the rocks. The subterranean waters that were circulating here at the time of the formation of the ore-deposits must have been much more energetic solvents, being heated by contact with the cooling masses of igneous rock, and probably deriving a certain amount of active and energetic mineralizing agents, such as fluorine, chlorine, etc., from these igneous masses at the time of contact. Hence it is fair to assume that the vein-materials in this region were originally derived from both recent and ancient eruptive rocks —a conclusion similar to that arrived at by Mr. Penrose, from his more exhaustive study of the ore-deposits of Cripple Creek."

The Occurrence and Treatment of Certain Gold Ores of Park County, Colorado. By B. SADTLER, pp. 848–853.

The Occurrence of Gold Ores in the Rainy River District, Ontario, Canada. By WM. H. MERRITT, pp. 853–863.

Other papers — such for example — as *The Microstructure of Steel and the Current Theories of Hardening*, by ALBERT SAUVEUR, have direct application to the broad domin of theoretical geology.

C. F. TOLMAN JR.

The Law of Mines and Mining in the United States. By DANIEL MOREAU BARRINGER and JOHN STOKES ADAMS. Little, Brown, & Co., Boston, 1897.

Although primarily a legal work this book possesses not a little interest and value to geologists in general and especially to those who have to deal with economic interests. It opens with a geological preface in which the various kinds of mineral deposits that are liable to be subjects of litigation are defined and their modes of occurrence and to some extent their origins are briefly stated, as these features are often decisive in the legal classification of the formations. The purpose of the work is to give a better appreciation of the reasons for the established legal distinctions relative to mineral deposits, insofar as these are based on differences in the nature, the mode of occurrence or the origin of the deposits. While the matter is not new to geologists and makes no pretension to exhaustiveness, its special point of view gives not a little freshness to the sketch. The legal classification of ore deposits is not without its suggestiveness to scientific students.

The body of the book opens with a chapter on property in minerals where there has been no division between the ownership of the surface and of the mineral below, followed by one on property rights where the title to the mineral or the right to take it out is vested in some one who is not the owner of the soil. It then treats of mineral leases and the rights and duties arising thereunder, and the modes of assignment and termination of leases. Chapters follow on the property of the sovereign and its grantees in minerals, for example, minerals in the beds of navigable streams or under public highways or in lands taken by eminent domain. There is also a discussion of the government's title and the granting thereof. A chapter is devoted to the discovery and location of claims, another to the extent of claims, and one each to the method by which claims are held, to the local mining rules and regulations, to the method by which title to mining claims may be terminated, and to the reloca-

tion of claims; also one each to the acquiring of a title before the patent and to the patent itself. The different kinds of claims, as lode claims, placer claims, lodes in placers, tunnel claims, mill sites and water right claims are systematically treated. Passing by some chapters on special themes we may note those on the rights of mine owners and of miners respectively, and the one on the application of equitable principles and remedies to mining operations. An appendix embraces the United States statutes relative to mineral deposits and the land office regulations. A very large number of cases are cited and briefly abstracted in illustration of the general treatment of the several themes. T. C. C.

The Science of Brickmaking: with some Account of the Structure and Physical Properties of Bricks. By GEORGE F. HARRIS, F.G.S. 160 pp. H. Greville Montgomery, London, 1897.

Professor Harris has presented in this little volume an admirable elementary treatise upon the science of brickmaking, which cannot fail to be of much value to the more intelligent class of brickmakers and clayworkers generally. The subject is logically and systematically discussed and is illustrated with a large number of local examples of brick-earths. The book contains much new information upon one of the most important economic subjects with which the geologist comes in touch. It is significant to see a man of Professor Harris' scientific attainments in the more theoretical and technical phases of geology turning his attention to so thoroughly practical a subject as that of brickmaking. Professor Harris rightly thinks that too many geologists do not sufficiently regard the economic aspects of their science, and he is preparing to present to the English-reading public still further contributions upon the practical side of geology.

The book opens with a discussion of the different types of brick-earths, which are classified as fluviatile, lacustrine and fluviatile, and marine. Following this are chapters devoted to the mineral constitution of brick-earths, and the behavior of the various minerals in the kiln. In this connection the author clearly points out that the chemical analysis does not always afford the needed information to the brickmaker, but that the physical constitution of the materials also has great influence in determining the value of the brick-earth.

The chemistry of brick-earths and the methods to be pursued in analyzing them are considered at much length. The micro-structure of bricks is presented in a manner to be of much aid to the practical brickmaker who is anxious to determine the texture of his product. The important question of the durability of bricks is also discussed. Among the tests which are mentioned by the author are the chemical composition of the brick, its absorptive capacity, its minute structure, its specific gravity, and its strength. Each of these subjects is discussed in some detail.

This information cannot but be highly beneficial to the brickmaker capable of appreciating the bearing which accurate scientific knowledge has upon his industry. Similar treatises to that of Professor Harris, with American illustrations, would be of much value to our own economic interests. The more our operators, whether in clay or other mineral products, come to realize their dependence upon scientific fact, and they will only realize it by the geologist interesting himself in their work, the better for the success of their endeavors, and the greater influence the scientific expert will have among practical men generally.

WM. B. CLARK.

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ABSTRACTS :